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7/25/68

QUANTITATIVE UTILIZATION OF ACTIVITY
DATA FOR INITIAL LAYOUTS

A THESIS

Presented to

The Faculty of the Division of Graduate

Studies and Research

by

Michael Pierce Deisenroth

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

Georgia Institute of Technology

March, 1971

QUANTITATIVE UTILIZATION OF ACTIVITY

DATA FOR INITIAL LAYOUTS

Approved:

Chairman

Date approved by Chairman: Mar 3, 1971

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation for the valuable guidance, criticism and encouragement given by Professor James M. Apple who acted as thesis advisor.

Appreciation is extended to the Thesis Committee, Dr. Douglas C. Montgomery and Professor Raymond K. Flege, for their constructive comments during this study.

A special debt is owed to my wife, Claudia, for her continuous encouragement and understanding during my graduate work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

SUMMARY

The objective of this study was to design a computer program to aid in developing an initial layout of the production areas within a manufacturing facility. It was intended that traditional considerations utilized in establishing layouts by conventional methods be included in the computer program.

The procedure followed was to preview the literature in the general area of plant design and specifically in the area of computer aided design. As the study progressed, it became apparent that most existing computer layout programs did not utilize input data that reflected the materials flow pattern within the facility. It was decided that the computer program should imitate the steps performed in a manual layout process. A further observation was that the computer program should not attempt to perform the entire layout process but should be limited to aiding the layout engineer in producing a final design. This somewhat limited scope was adopted to insure a result that would be useful to the general practitioner.

The program establishes initial block layouts by heuristic arguments, utilizing input data in one of three basic forms:

1. A list of items of material and the sequence of flow of each item.

2. A From-To Chart indicating the materials flow patterns.

3. A penalty matrix.

The program begins with a blank or empty layout grid and enters departments one at a time until all departments have been placed in the layout. Three methods of selecting the sequence of departments to be entered are available, thus providing three alternative suggestions to aid the layout engineer in establishing a final layout design. A block layout is produced by the program for each alternative layout.

CHAPTER I

HISTORICAL INTRODUCTION

The function of the layout design process is to arrange the various activity areas involved in processing the material from the raw state to the finished product state. Simply stated, the layout process allocates areas within an existing or potential building for specific manufacturing purposes and at the same time considers the necessary relationships with supporting facilities. A layout is almost always associated with the flow of materials. Consequently plant layout design is usually concerned with materials handling cost. The contribution of the layout procedure to the processing of the material is the development of an arrangement which will minimize the material flow cost. Other considerations are usually introduced to subjectively select between layouts with low handling costs.

A general survey of the literature is presented to acquaint the reader with work that has previously been done in the layout design area. A detailed look at available computerized layout programs will be presented in the next chapter.

The problems of facilities design are as old as manufacturing itself. Initial efforts in layout work were mostly trial-and-error arrangements, although rising labor costs and competition forced the layout designer to adopt more systematic procedures. Many forms and heuristic procedures have been designed to accumulate the necessary data and many "rules-of-thumb" have been developed to utilize these procedures to take the guesswork out of the layout design. However, emphasis has recently shifted from the subjective decision process toward more quantitative techniques. In general, many of these techniques have been based on the Travel or From-To Chart, which provides a summary of data on the movement of materials between department pairs.

Travel Charts

Cameron first considered the concept of a Travel Chart, which was to be used to "visualize and clarify complex inter-department . . . material movements" (5).* This chart, which is similar to the mileage chart found on a roadmap, utilizes numeric quantities as measures of the materials flow *from* each of the relevant departments *to* all other departments under consideration. Cameron pointed out that in addition to providing a quantitative measure of materials flow between areas, this total can also be used to show the dependency of one manufacturing area upon other contributing areas. Emphasis on the concept of materials flowing *from* one department *to* another has brought about the usage of From-To Charts to replace the original name.

A procedure utilizing the From-To Chart for solving arrangement problems in a process type layout was developed by Smith (24). A significant contribution was made in that the measure used to evaluate a layout was obtained by adding the products of each element in the Chart

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*Numbers enclosed in parentheses indicate references listed in the Bibliography.

multiplied by the distance between the respective departments. Smith used the order in which the departments were listed to represent a straight line arrangement of departments. Furthermore he assumed that the distance between adjacent areas could be considered as a unit distance and that all unit distances were equal. The assumptions extremely limited application of his technique to practical problems.

Lundy (17) objected to Smith's treatment of backtracking being considered twice as bad as forward movement. Lundy pointed out that this was only true in the straight line arrangement and not in a general case. The cost of any move, forward or backward, was associated with physical characteristics of the move such as frequency, weight, handling method and distance. Penalties added for backtracking are an erroneous assumption leading to wrong conclusions. Lundy also suggested that schematics or rough layouts be used to determine distances between departments so that the technique could be used on all process type layouts.

Charts Showing Relative Relationships

Farr (7) introduced the From-To Chart under a different name--the Cross Chart. The measure associated with each department pair is obtained by combining the Flow Diagram and the Operation Process Chart. The quantitative data are then grouped into four classes for evaluating alternative layouts. The divisions considered by Farr were:

3--should be very close

2--should be near one another

1--present location satisfactory, and

+--desirable that they be near by.

Although somewhat easier to utilize in complex situations, this method limits the decision process to qualitative measures.

A chart, very similar to Farr's Cross Chart, was developed by Muther (19). The Relationship Chart replaced the quantitative measure with purely qualitative "values" and considers the relationship *between* department pairs. The relationship is expressed by letters, traditionally A-E-I-O-U-X, and the chart is symmetric, if shown as a square, or can be expressed in triangular form.

Procedures for Utilizing the Charts

A complete procedure for arriving at an area layout was developed by Buffa (3). The position of each work center was determined by interpreting the data in a From-To Chart. A matrix, which combined the size and frequency of movement of various parts to be manufactured, was presented for arriving at the measure of material flow. The measure of movement from one department to another was then combined with the flow in the reverse direction to establish a measure of flow between the given pair. The flow between all pairs was transferred to a schematic diagram for consideration of spatial arrangement. The significance of Buffa's work is that each work center is analyzed with respect to its relationship to all other departments. Unfortunately, in obtaining the ideal schematic diagram, Buffa was forced to disregard differences in departmental area requirements.

In 1958, Llewellyn (16) combined the works of Smith (24) and Buffa (3) in a practical problem. Distances were measured from a scale layout but included travel to and from an aisle and not direct center to center movement. The layouts were compared to an "optimum" to establish their efficiencies. Although the aisle location and optimum layout were somewhat arbitrary, the example demonstrated two important points: (1) that backtracking would be automatically penalized by using actual distances and an additional penalty was not necessary, and (2) that improvements in the layout were made by locating highly related departments close together.

Gani (8) developed a quantitative procedure, based on the From-To Chart, to plan and/or analyze material flow and activity relationship problems. The procedure involves the development of an In-Flow Chart and an Out-Flow Chart. Specific details of this method will be mentioned later. The most important point to note here is that actual handling cost, in dollars, was finally introduced into the From-To Chart. Each entry combined (1) the number of moves per time period, (2) the distance moved and (3) a predetermined cost per foot to move the specific materials by a predetermined method.

Mathematical Formulations

Recent research has lead to the application of mathematical programming techniques to the general problem in hopes of finding a computationally feasible optimal seeking algorithm. Certain basic assumptions can reduce the problem to a constrained quadratic programming formulation. Gilmore (9) and Lawler (13) have suggested branch and bound procedures for producing optimal results for these formulations. Although the solution procedures are valid, computational limitations, even using high speed computers, restrict solutions to only the simple problems. Both authors agree that their procedures are not applicable to large problems.

Lawler (13) has utilized the Koopmans-Beckmann (12) quadratic formulation to restrict the problem to an integer linear programming formulation. While mathematically correct, the solution is still computationally infeasible.

Even though these areas offer some promise for future solutions, at present the general practitioner finds even the assumptions (n , departments of equal area) somewhat unrealistic if not totally impractical.

A number of articles can be found which discuss the problems of locating new equipment with respect to existing machinery. The normal assumption is that alternative locations are represented by points in a plane, and the problem is one of assigning equipment to alternative locations. Various approaches to this problem can be found in the literature (18,20,22,25). A discussion of these articles, although definitely related to the layout process, has been omitted due to its lack of bearing on the specific problem under study.

CHAPTER II

SOME EXISTING LAYOUT PROGRAMS

When the number of departments to be considered becomes large or the material flow patterns become numerous or complex, the volume of data to be considered in selecting or designing a layout is enormous and traditional layout tools become unmanageable. Recently researchers have turned their attention to using heuristic computer models to aid in the layout process. Three such models have found fairly wide acceptance and some use in industry and will be reviewed in this chapter. A fourth concept was introduced at Georgia Institute of Technology by Gani (8) and is also included in this review because of its relevance to the program developed in this thesis.

CRAFT

One of the first computer models that was developed for the general layout problem was CRAFT (Computerized Relative Allocation of Facilities Technique). The Buffa-Armour-Vollman (2,4) model is a heuristic approach, which produces a block layout by continuously improving on a previous layout. The concept consists of taking a given layout and exchanging the two departments which best improve the layout. This procedure is repeated until no exchange will result in an improved condition. The measure by which a layout is evaluated is its total handling "cost" which takes into consideration the volume of the material flow, the cost of each flow and the distances involved.

Input Data

The input data requirements for the CRAFT routine can be divided into three components:

1. A matrix or table of interdepartmental material flows is necessary to establish the volume of material flowing between each pair of departments per unit time.

2. A matrix of handling costs for each pair of departments between which material flows.

3. An initial or trial layout which the algorithm will try to improve by exchanging the positions of pairs of departments.

Once the initial layout has been read by the input routine, the program calculates the center of each departmental area and the distance between each pair of departments is established. This distance, along with the volume flow matrix and the cost matrix, is used to calculate the total material handling cost of the layout. The program permits the user to specify that some departments are fixed and therefore not eligible for exchange.

Algorithm

The general flow of the program is shown in Figure 1. The algorithm tests all possible exchanges of departments and then makes the exchange which is estimated to reduce the total materials handling cost most. A pair of departments is considered for exchange if it meets one of the following criteria:

1. Both Departments are the same size.

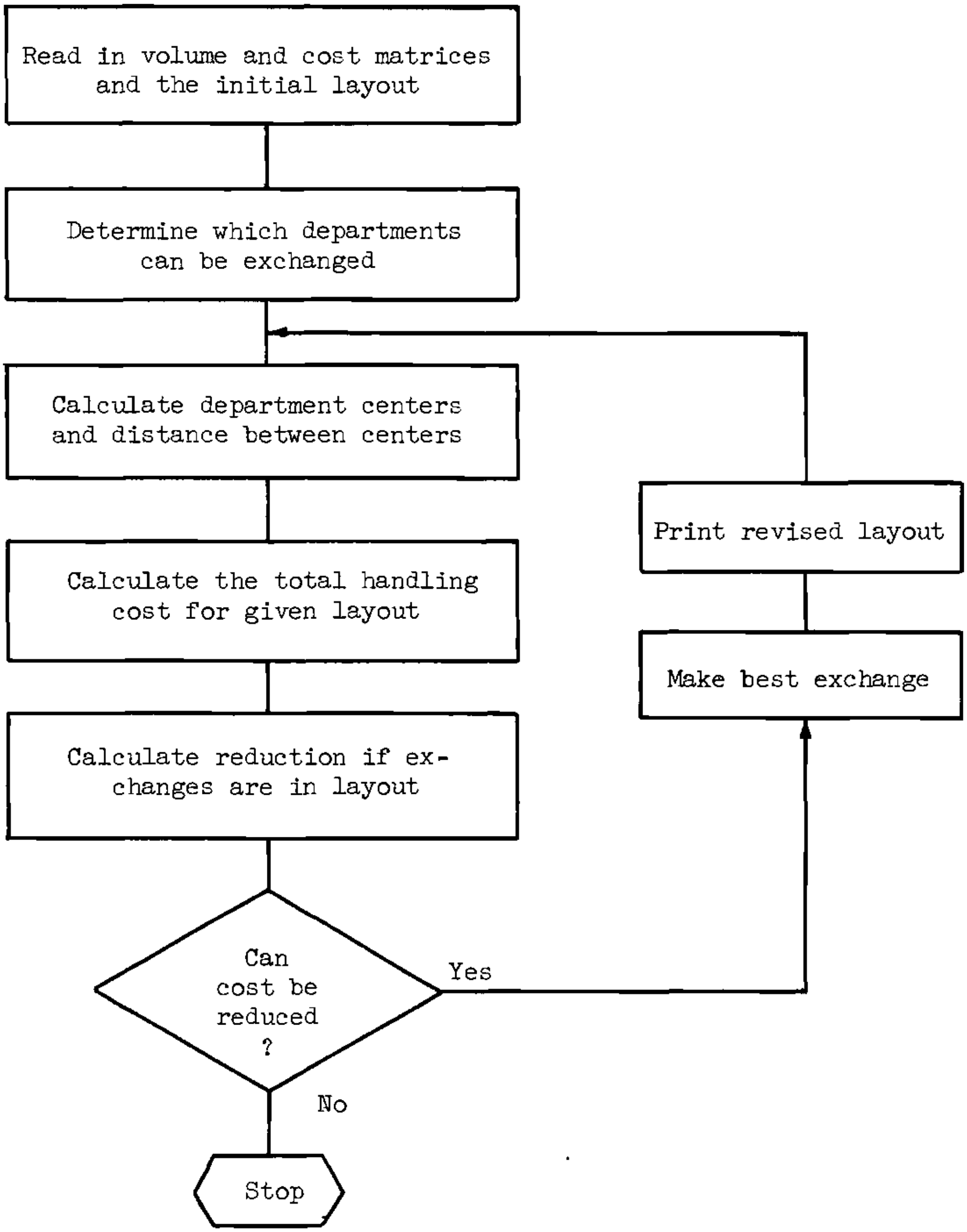


Figure 1. General Flow for CRAFT Program

2. They have a common border.

3. They both border on a common third department.

The first two conditions are used for a "two department" exchange while the third involves a "three department" relayout. CRAFT offers the user the choice of which of the exchanges is to be used:

1. Two department moves only.
2. Three department moves only.
3. Two department moves followed by three department moves.
4. Three department moves followed by two department moves.
5. Choose best of two or three department moves at each iteration.

To estimate the savings that might result from exchanging two departments, it is assumed that the resulting center of each department, after the exchange, would be the present center of the other department. If the pair is selected for the actual exchange and the new centers do not produce a reduction in the cost, the exchange is not made and some other exchange is tried.

Output

The output includes the volume flow matrix, the cost matrix and a third matrix, which is an element-by-element product of the first two matrices, is also printed. A spatial arrangement is printed to indicate the initial and final block layouts (see Figure 2). CRAFT will print the intermediate layouts that are encountered if the user so desires.

	1	2	3	4	5	6	7	8	9	10
1	J	J	J	J	J	J	J	J	L	L
2	J	J	J	J	J	J	J	J	J	L
3	I	I	J	M	M	M	M	M	F	F
4	H	H	J	J	M	M	M	M	F	F
5	H	B	A	A	A	G	G	G	F	F
6	B	B	A		A	G		G	F	F
7	B	B	A	A	A	G		G	F	F
8	B	B	C	C	C	G	G	G	F	F
9	B	B	D	D	D	D	D	E	F	F
10	B	B	D				D	E	E	K
11	D	D	D				D	E	E	K
12	D	D	D	D	D	D	D	E	E	K

Figure 2. Example of CRAFT Layout (Lines Added for Clarification)

ALDEP

Evans and Seehof (23) developed a simple procedure ALDEP (Automated Layout DEsign Program) to generate layouts of up to three floors by a random process. The program first established the necessary files for constructing a layout. In addition to department area, a preference matrix is necessary. This matrix indicates the priorities that should be given to locating areas adjacent to each other. After the processing of the input data is completed, the program develops a predetermined number of random layouts and scores or evaluates each one. The layout score is the summation of the preference values for adjacent departments. The flow chart is shown in Figure 3. Layouts meeting a predetermined minimum score are printed in block form.

Input Data

The input data for an ALDEP run is divided into four sections:

1. Control cards are necessary to specify the building description, the minimum score a layout must have before it is printed, and the number of layouts to be generated.

2. The area requirements that are necessary for each department.

3. The departmental preference matrix used in the main algorithm.

4. A preassignment list--since departments may be preassigned to a specific floor or they may be preassigned to an exact location.

Algorithm

After all the preliminary processing is completed, the specified number of random block layouts are produced by a two-step process. First the departments are separated for assignment to each floor of the

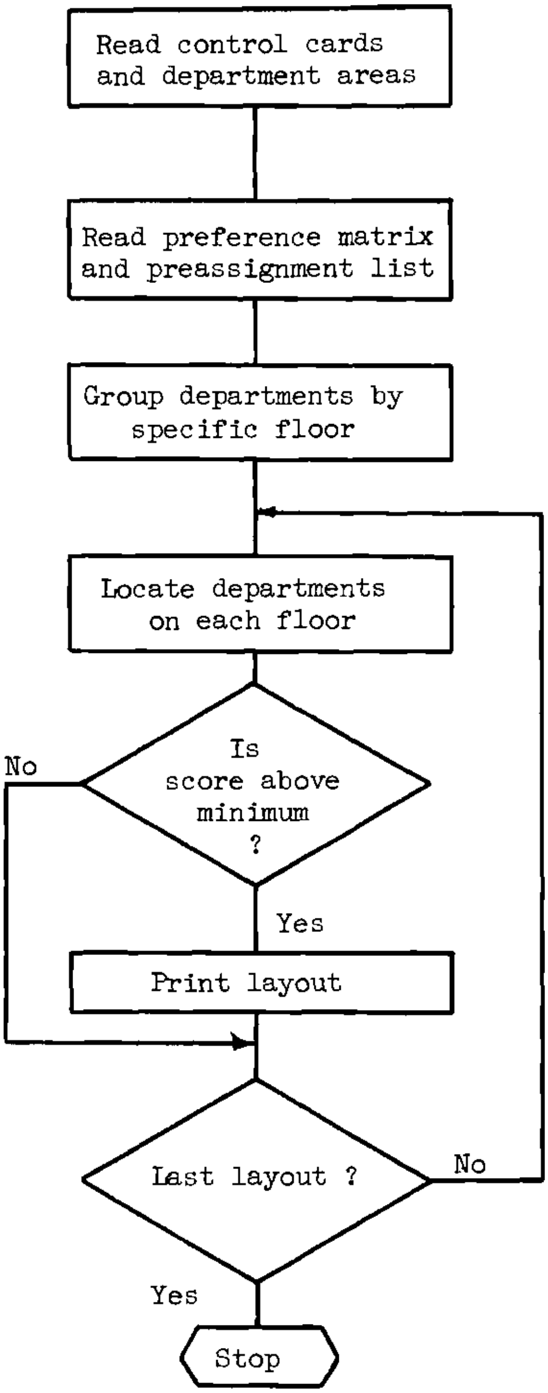


Figure 3. General Flow for ALDEP Program

building. Once the departments have been divided, each floor layout is produced, independent of the other floors.

A modified random selection technique is used to lay out each floor. Initially, a department is selected at random from those that were not preassigned a specific location. After the selected department is processed, the preference matrix is searched to find a department with a "demand preference" or highest priority relation with the last department selected. If a department is found with a demand preference, that department is selected for placement next provided it is not already in the layout. If no department is found with a high preference, a department is selected for placement randomly from those not already processed. This procedure is repeated until all departments are in the layout for that particular floor. The other floors are processed in the same manner.

Output

After each layout is produced, the program calculates its score by adding the preference values for adjacent departments. If the block layout meets the minimum score specified on the first control card, it is accepted and a spatial layout is printed as illustrated in Figure 4. Since each layout which meets the criterion is printed, the user is furnished with a set of different layouts which he can evaluate.

The authors suggest that better layouts are obtained by using the design program in stages. The planner should analyze the first layouts and, with information obtained from these layouts, assign particular departments to specific locations. This information could then be

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	11	11	9	9	9	9	5	4	4	4	10	10	10	10	10	10	0
0	11	11	9	9	82	82	5	5	4	4	10	10	10	10	10	10	0
0	11	11	99	99	99	99	99	99	99	99	99	99	99	99	10	10	0
0	11	11	99	83	83	9	5	5	4	4	10	10	10	99	10	10	0
0	11	11	99	9	9	9	5	5	4	4	10	10	10	99	0	7	0
0	11	11	99	9	9	9	5	5	4	4	4	4	7	99	7	7	0
0	11	11	99	9	9	9	5	5	4	4	4	83	83	99	7	7	0
0	11	11	99	99	99	99	99	99	99	99	99	99	99	99	7	7	0
0	11	11	9	9	9	9	5	5	4	4	4	4	7	7	7	7	0
0	11	11	11	11	5	5	5	5	4	4	4	4	7	7	7	7	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	6	6	6	81	81	81	3	3	3	3	8	8	8	8	0	0	0
0	6	6	6	81	82	82	3	3	3	3	8	8	8	8	8	0	0
0	6	6	99	99	99	99	99	99	99	99	99	99	99	99	8	8	0
0	6	6	99	83	6	6	3	3	2	2	2	2	8	99	8	8	0
0	6	6	99	83	6	6	3	3	2	2	2	2	8	99	8	8	0
0	6	6	99	6	3	6	3	3	2	2	2	2	8	99	8	8	0
0	6	6	99	6	3	3	3	3	2	2	2	83	83	99	8	8	0
0	6	6	99	99	99	99	99	99	99	99	99	99	99	99	8	8	0
0	6	6	6	6	3	3	3	84	84	1	1	1	8	8	8	8	0
0	6	6	6	6	3	3	3	84	84	1	1	1	8	8	8	8	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

Figure 4. Example of ALDEP Layout (Lines Added for Clarification)

submitted and more random layouts produced. The procedure can be repeated until the complete building is assigned.

CORELAP

COmputerized RElationship LAyout Planning (CORELAP) was developed by Lee and Moore (14,15). The program is a heuristic, path-oriented method of establishing an initial block layout. No building shape is specified, thus permitting the generation of department configurations and locations before the building configuration is defined. The logic used in arriving at the final layout utilizes the Relationship Chart developed by Muther (19). Specific floor area requirements are also necessary to establish the size of each department. The program begins with a blank or empty layout grid and locates departments one at a time until all departments have been placed in the layout. Since this is a path-oriented process, a given set of input data will always produce the same final layout.

Input Data

Three components of input data are necessary for the CORELAP algorithm:

1. The number of departments to be used and a maximum length-to-width ratio is specified which restricts the maximum length of the layout to be produced.

2. A Relationship Chart, which is used to calculate the Total Closeness Rating (TCR) for each department. The TCR represents the summation of a department's relationship to all other departments in the layout.

3. The area required by each department.

<u>Algorithm</u>

The main algorithm processes departments by answering two questions:

1. Which department has the privilege of being placed next into the layout?

2. How is it entered into the layout?

The first department to enter the layout is the one with the highest TCR value and it is placed in the center of the layout and designated "Winner." Next the relationship matrix is searched to find a department that has an "A" (maximum) relationship with this department. Any ties that might result between available departments are broken by selecting the one with the highest TCR value. The selected department is placed in the layout and designated "Victor."

The program then returns to find another "A" relationship with the previous Winner and places that department in the layout. This procedure is continuously repeated. If an "A" relationship cannot be found, then all Victors are checked to see if they have an "A" relationship with an available department. If an "A" relationship is found, then the Victor becomes the new Winner and the entering department is placed in the layout. If neither the Winner nor any Victor produces an "A" relationship, then the minimum acceptance level is reduced and a new search begins.

A general "sweep" routine is utilized in the placement of a Victor. This routine examines the layout matrix for available squares adjacent to the Winner. If space is available adjacent to the Winner, then the Victor is located in this space. If space is not available adjacent to the Winner, the sweep routine inspects squares one step further away from the Winner and repeats the process. Figure 5 shows the flow chart for the program.

Output

As each department enters the layout an intermediate layout is produced. This permits the user to follow the buildup of the final layout which will aid in adjusting this layout to an acceptable building shape. Figure 6 illustrates one iteration of a CORELAP program.

PLANET I

A series of special projects at Georgia Institute of Technology, initiated by Gani and Apple (8), and further developed by Devis (6) and Klein (11) has resulted in a computerized technique which calculates departmental relationships for use in developing an Area Allocation Diagram. Plant Layout Analysis aNd Evaluation Technique, referred to subsequently as PLANET I, did not produce a block diagram as do the three programs reviewed above, but instead it stressed the fundamental importance of the practicality of input data involved in a production-type layout.

Input data was in the form of a From-To Chart, where each element was the product of (1) the frequency of materials movement, (2) the distance between the specific pair of departments, and (3) the cost per move for a predetermined method of handling. Since the final distance between departments was not an available input, an ideal distance was

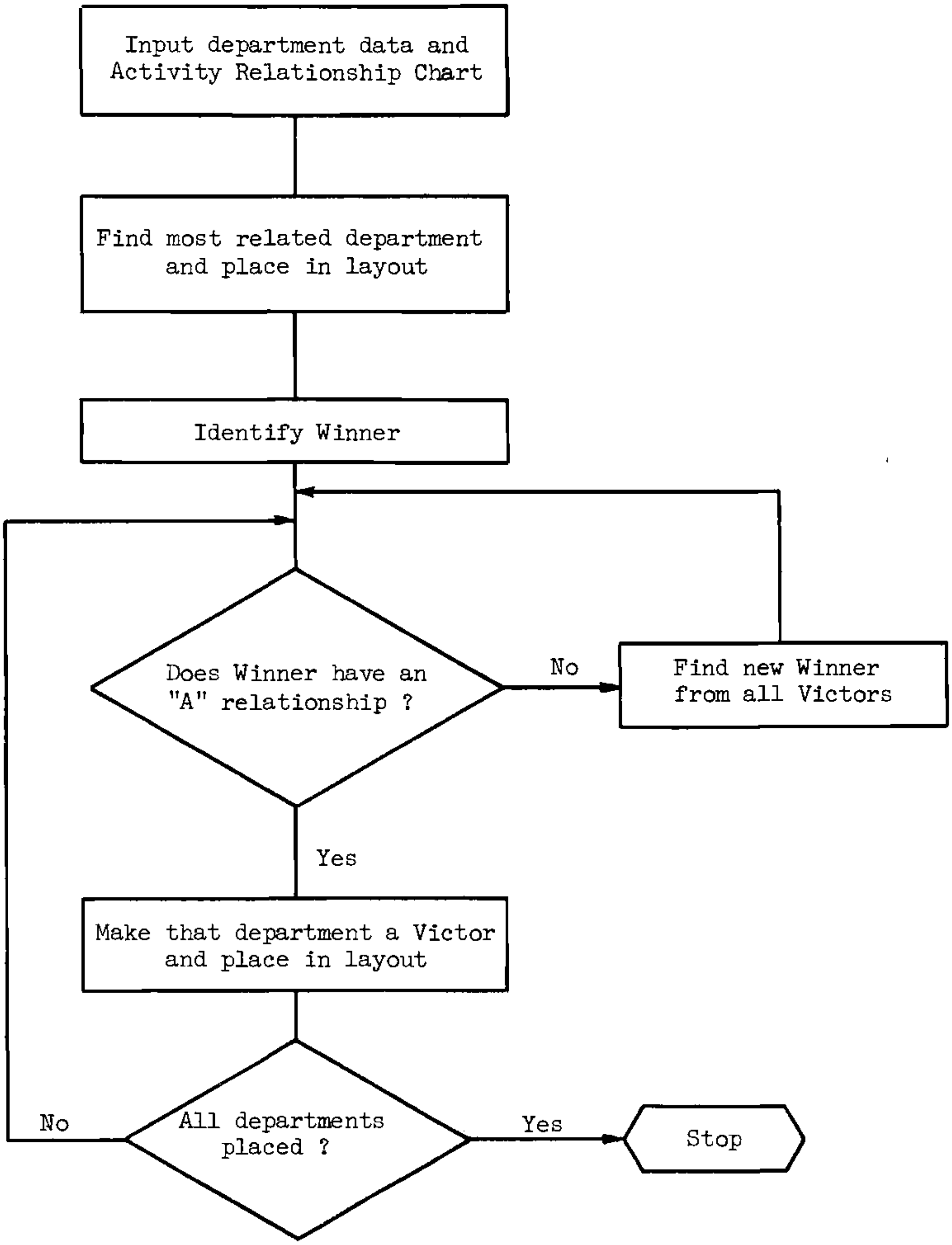


Figure 5. General Flow for CORELAP Program

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	19	19	19	19	19	19	0	0	0	0	0	0	0
0	0	0	17	17	17	19	19	19	19	0	0	0	0	0	0	0	0
0	0	0	17	17	17	17	19	19	19	16	16	15	15	0	0	0	0
0	0	0	17	17	17	18	19	19	19	16	15	15	15	12	0	0	0
0	0	0	17	17	11	11	11	11	11	11	16	15	15	12	12	0	0
0	0	0	17	17	11	11	11	11	11	11	21	15	15	12	12	0	0
0	0	14	14	20	11	11	11	11	11	11	21	21	15	12	12	0	0
0	0	14	14	14	14	11	11	11	11	0	0	15	15	12	0	0	0
0	0	14	14	14	14	22	13	0	0	0	15	15	15	15	0	0	0
0	0	0	0	13	13	13	13	0	0	0	0	0	0	0	0	0	0
0	0	0	0	13	13	13	13	0	0	0	0	0	0	0	0	0	0
0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 6. Example of CORELAP Layout--Taken from the CORELAP Users' Manual by J. M. Moore and R. N. Lindquist

initially assumed. The ideal distance between two departments assumed that they were square and placed adjacent to each other. An Inflow Interrelationship was then calculated which expressed the flow from the ith department to the jth department as a percentage of the total flow into the jth department. This value was then used as an index to state the preferences of the specific departments for location near other departments. Those department pairs with a high Inflow Interrelationship had a higher preference than those with lower values. An Outflow Interrelationship was also calculated.

After PLANET I computed the Inflow and Outflow Interrelationships, the user constructed an Activity Relationship Diagram as the basis for establishing a layout (see Figures 7, 8 and 9).

Departments	Degree of Closeness		
	First Class	Second Class	Third Class
1	3, 5	8	6, 2
2	10, 4, 3, 6		
3	10, 4	5, 2, 6	
4	10, 7	9, 2, 6	
5	10, 4		
6	10, 4		
7	10		
8	3		
9	4		
10	3, 6, 4, 7	2, 5	

Figure 7. Typical Classification of Departments Resulting from PLANET I

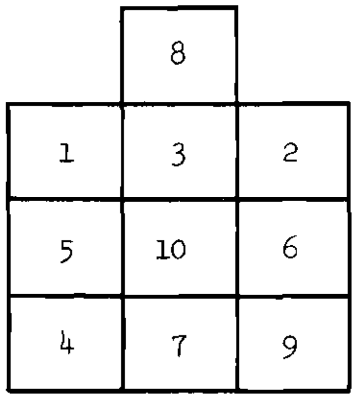


Figure 8. Activity Relationship Diagram--Based on the Departmental Relationships Given in Figure 7

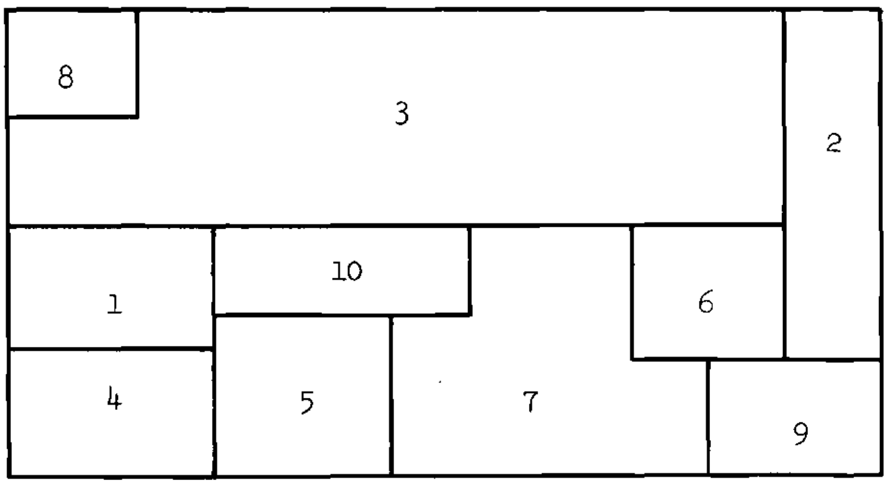


Figure 9. Area Allocation Diagram--Developed by the Engineer from the Activity Relationship Diagram in Figure 8

Once the Activity Relationship Diagram was established, measured distances between department centers were used to refine the calculations of interrelationships by means of a new Activity Relationship Diagram and to evaluate the necessity of adjusting the layout based on actual distances.

Conclusions

Other computerized layout programs are in existence; however, their availability or limited use has excluded them from this review. None of these methods produces an optimal layout. However, all are logical in nature and should be thought of only as tools to guide the user toward a solution to his problem. The appropriateness of a particular program depends upon the specific application. Figure 10 summarizes some of the basic considerations in using the four programs reviewed.

A close look at Figure 10 will show that one area of application is missing--initial layouts of production facilities. PLANET I represents the beginning of such a program but fails to produce a spatial arrangement. It is the purpose of this thesis to refine the PLANET I algorithm to provide a program utilizing quantitative input data and resulting in a spatial arrangement.

	CRAFT	ALDEP	CORELAP	PLANET I
Basis for Algorithm	Quantitative input Flow and cost Heuristic algorithm	Qualitative input Preference matrix Random layout	Qualitative input Relationships chart Heuristic algorithm	Quantitative input Materials flow data Matrix manipulation
Building Shape	Initial input one floor	Initial input up to three floors	Not specified by user	No building input or output
Scoring Technique	Considers $/ft. times distance moved for all department pairs	Summation of preference values for adjacent department only	No score produced	Materials flow cost
Alternative Designs	Produces different layouts by changing exchange criteria	Many	None	---
Maximum Number of Departments	40	63	45	---
Best Application Area	Rearrangement of layouts in fixed buildings and/or existing layouts	Service or non-production facilities	Initial layout office and production facilities	Production facility

Figure 10. Comparison of Computer Programs

CHAPTER III

THE PLANET II LAYOUT PROGRAM

This chapter presents a general description of the methodology and flow of the program developed in this thesis. A complete listing of the program is included in the Appendices.

This program does not design a total layout for a new production facility nor does it select the best layout from all possible arrangements. It is intended as a tool to help the layout engineer in the initial stages of the layout design process. Based on the flows of different products or parts between various activities, the program utilizes a two-step heuristic algorithm to arrive at rough layouts with low materials handling cost. These layouts represent only suggested orientations of the activity areas and must be molded into a logical building configuration by the layout engineer.

Measure for Evaluation

The layout process is concerned with the establishment of a spatial arrangement of the activity areas or departments within the facility. In a production environment the materials flow pattern is of primary concern when arranging the production activities, since materials handling does not usually increase the value of a product but is normally a burden of the production facility. It is therefore desirable to minimize the cost of materials handling when arranging the departments within the facility.

Nonquantitative factors often influence the construction or the selection of a layout. One common method of including these factors in the determination of a final layout is the establishment of constraints which all alternatives must fulfill. Alternatives that are compared for minimum cost must meet these constraints. Another method of including these factors is to adjust the minimum cost layout to satisfy these qualitative objectives. Regardless of the method used to consider qualitative factors, materials handling cost is the primary quantitative factor concerned.

As the number of different products produced within a specific facility increases, the combination of the flow patterns becomes very complex. This in no way reduces the importance of the flow of materials, however, traditional methods of evaluation are complicated by the increased data. This program is designed to reduce the complexity of this problem by processing data from many individual flow patterns and producing a meaningful relationship between departments to be used in planning a layout. The objective of the program is to suggest spatial arrangements which would have low materials handling costs.

Input and Scoring Techniques

The basic input data can be divided into two classifications:

1. Characteristics of the departments.
2. Characteristics of the material flow patterns.

Other input information is necessary, but only for application of the computer program and is not presented in this chapter. See Appendix II for complete information on input requirements.

Characteristics of Departments

A basic input to any layout problem is a list of the departments to be included in the layout and the area requirements for each. Figure 11 illustrates a typical list of the input information necessary for this section of the program.

Department Number	Total Area Required	Description of Department
1	729	Rough Stores
2	984	Mill
3	3944	Lathe
4	1229	Drill
5	234	Grind
6	301	Press
7	138	Saw
8	468	Final Inspection

Figure 11. Input Data for the Activity Areas

Since the output of the model is only intended to suggest relative placements of these departments, restrictions on specific shapes are not necessary as input data.

Material Flow Patterns

The works of Gani (8), Devis (6), and Klein (11) with PLANET I had a strong influence on this section of the program. Therefore continuous references to Gani will be made to show the similarities and differences between the two programs.

The basic approach to analyzing the movement of materials within a facility is to examine each material as it moves between the various departments. Muther (19) states that

> Generally speaking the layout man should start with an Operation Process Chart in any layout work. Even if making a half-dozen different products, begin with charts for each one.

When the number of products or parts becomes too large for individual charts, a Multi-Product Process Chart can be used to summarize the individual Process Charts.

Since the program was developed to apply to this type of situation, the input data is structured in the format of a Multi-Product Process Chart. The program utilizes a list of the parts or products which flow through the facility and the sequence of flow of these items. The Parts List utilizes the department number assigned in Figure 11 in the sequence of flow. Figure 12 illustrates the initial basic data required for the program and the Multi-Product Process Chart constructed from the data. Thus part number 03 begins in department number 1, moves from department 1 to department 2, moves from department 2 to department 7, and finally moves from department 7 to department 8. Without the input data on the area requirements of the departments, this flow information would be meaningless.

Gani felt that the sequence of flow was not sufficient and that other characteristics of each flow should be used as input data. Two such factors--cost of movement and frequency of movement--were included in the earlier work and were adopted in this study.

Part Number	Sequence
01	1 - 2 - 3 - 6 - 5 - 8
02	1 - 7 - 4 - 7 - 6 - 8
03	1 - 2 - 7 - 8
04	1 - 3 - 4 - 7 - 8

Parts List and processing data used for constructing the Multi-Product Process Chart shown below.

Operations		Part Numbers			
		01	02	03	04
1	Rough Stores	10	10	10	10
2	Mill	20		20	
3	Lathe	30			20
4	Drill		30		30
5	Grind	50			
6	Press	40	50		
7	Saw		20 40	30	40
8	Final Insp.	60	60	40	50

Multi-Product Process Chart.

Figure 12. Multi-Product Process Chart

The cost of movement is an estimate of the handling cost of moving a unit load of the specific material over some fixed distance. Obviously some method of movement, as well as a unit load size must be considered in making this estimate. Characteristics of the material, such as shape, size, weight and durability must be considered in selecting the handling method and in making this estimate.

The frequency of movement reflects the number of unit loads that are to be moved in a unit time period. The quantity considered for a unit load and the expected production quantity per unit time are necessary to calculate this factor. Figure 13 shows the development of these two factors. Also, a column indicating the number of moves in the sequence has been added for checking purposes.

Part Number	Number of Operations	Frequency of Move	Cost/Move	Move Sequence
01	6	4	0.025	1-2-3-6-5-8
02A	4	4	0.010	1-7-4-7
02B	3	2	0.025	7-6-8
03	4	4	0.015	1-2-7-8
04	5	8	0.010	1-3-4-7-8

Figure 13. A Revised Parts List (See Appendix III for Information on Cost/Move Data)

Since the addition of the cost per move column presupposes a particular method of handling and a unit load size, it may be desirable to break the flow of some parts into sections which have common handling characteristics. For example, part number 02 has a sequence of flow of 1-7-4-7-6-8; however, two different handling methods are anticipated. The sequence 1-7-4-7 will be handled by one method while the sequence 7-6-8 will be handled by a different method. Figure 13 indicates this by showing two different parts 02A and 02B which have different costs and frequencies.

Data Manipulation

Before the main algorithm can initiate the layout process, the data must be translated into a format useful to the algorithm. An index of the movement cost for a specific part can be obtained by multiplying the frequency of movement by the cost per move per foot of travel. Consider part number 01. The cost of flow can be found as follows:

$$4 \text{ moves/day} \times \$0.025\text{/move/100 feet of travel} =$$
$$\$0.10\text{/100 feet of travel/day}$$

Another way of saying this is that part number 01 will increase the daily materials handling cost by $0.10 for every 100 feet of distance over which it must travel. The flow path of this part could be drawn on any proposed layout and the materials handling charges for it could be calculated. Since the number of parts could be numerous, this method is not practical and a better way of indicating the flow of all the parts is needed.

A From-To Chart is used to summarize the flow costs of all parts from each department to the other departments in the layout. Stating this mathematically

$$C_{ij} = \sum_{\text{all } k} c_{ijk} \qquad \text{for all } i \text{ and } j$$

where C_{ij} is the total flow cost from the ith department to the jth department, and

c_{ijk} is the flow cost from the ith department to the jth department for the kth part.

The program combines the flow costs and sequence of flow for each part to produce the total flow. Figure 14 is the From-To Chart of total flow cost for the data given in Figure 13. The elements of this chart express the flow in one direction only. To get a true picture of the flow in both directions, the material flow cost in one direction must be added to the flow cost for those moves made in the reverse direction. The sum produced in this manner is a measure of the material flow between the two departments. Figure 15 illustrates the Flow-Between Cost Chart for the sample calculations. The elements of this chart are symmetric about the main diagonal and represent the penalty or cost of separating two departments.

The Flow-Between Cost Chart places the flow between two departments in the proper perspective, by permitting a comparison to all other flows in the facility. If the flow between cost is larger for one pair of departments than for another, it is more important to locate the first pair closer together, since this cost is an index of the cost per foot of separation.

The Flow-Between Cost Chart produced by this program is identical to a combination of the volume flow matrix and the cost matrix used in the CRAFT routine. However, the input process suggested here reduces

		TO							
		1	2	3	4	5	6	7	8
FROM	1	-	.16	.08	-	-	-	.04	-
	2	-	-	.10	-	-	-	.06	-
	3	-	-	-	.08	-	.10	-	-
	4	-	-	-	-	-	-	.12	-
	5	-	-	-	-	-	-	-	.10
	6	-	-	-	-	.10	-	-	.05
	7	-	-	-	.04	-	.05	-	.14
	8	-	-	-	-	-	-	-	-

Figure 14. From-To Chart of Total Flow Cost

	1	2	3	4	5	6	7	8
1	-	.16	.08	-	-	-	.04	-
2	.16	-	.10	-	-	-	.06	-
3	.08	.10	-	.08	-	.10	-	-
4	-	-	.08	-	-	-	.16	-
5	-	-	-	-	-	.10	-	.10
6	-	-	.10	-	.10	-	.05	.05
7	.04	.06	-	.16	-	.05	-	.14
8	-	-	-	-	.10	.05	.14	-

Figure 15. Flow-Between Cost Chart

the uncertainty of the elements of the matrix. All that is necessary to calculate an estimate of the materials handling cost of a layout is the distances between the pairs of departments.

Scoring Technique

One of the best possible ways of comparing layouts would be to calculate the materials handling costs associated with each arrangement of the departments. Since the flow-between cost represents the cost per foot of separation between all pairs of departments, the materials handling cost associated with a layout could be estimated by summing the products of flow-between costs and the appropriate distances.

A general formula for the total materials handling cost estimate is given below

$$TC = \sum_{i=1}^{n-1} \sum_{j>i} C_{ij} d_{ij} \qquad i,j=1,\ldots,n$$

where

- TC is an estimate of the total handling cost for the given arrangement,
- C_{ij} is the flow between cost for the ij pair,
- d_{ij} is the distance between the ith department and the jth department, and
- n is the number of departments concerned.

Distances between each pair of departments are computed, based on their respective centers. The measure of distance used is based on straight-line movements parallel to the axes of the layout. It was felt that this distance would more closely approximate an actual flow path than would a shortest path or direct distance measure. Figure 16 illustrates this method of distance measurement.

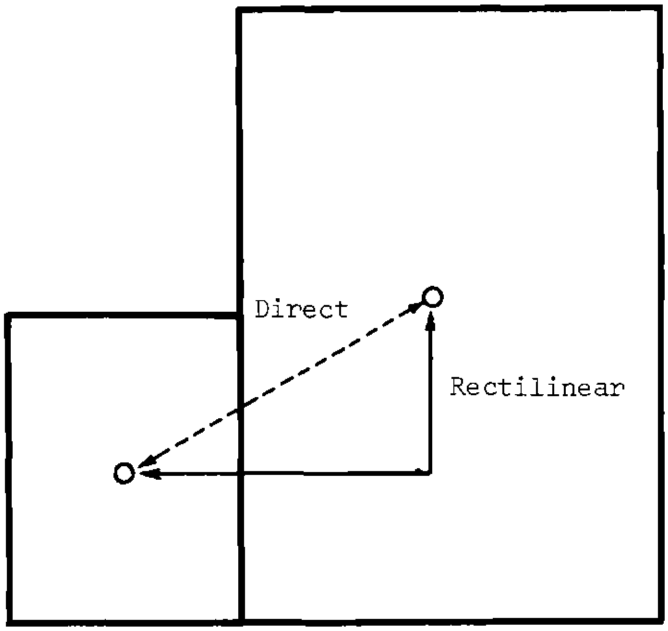


Figure 16. Method of Measuring Distance

The Algorithm

The problem to be solved by the algorithm is to arrange the set of activity areas or departments in such a manner as to minimize the total materials handling cost. The algorithm utilizes the area requirements and the Flow-Between Cost Chart as input data. To accomplish the task of creating a spatial arrangement, it repeatedly answers two basic questions until all areas have been assigned to specific locations:

1. What department should be selected next for placement in the layout?

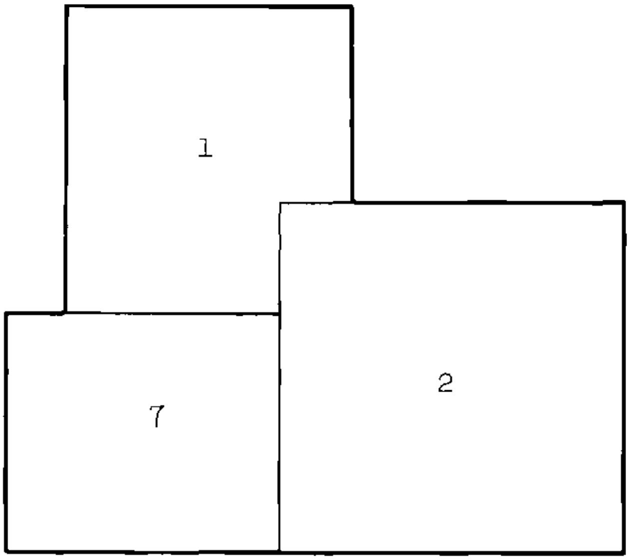
2. Where should it be placed?

The algorithm begins with a blank or empty layout grid and enters departments one at a time until the last department has been assigned a specific location. Figure 17 illustrates a layout before and after department number 5 is assigned a location.

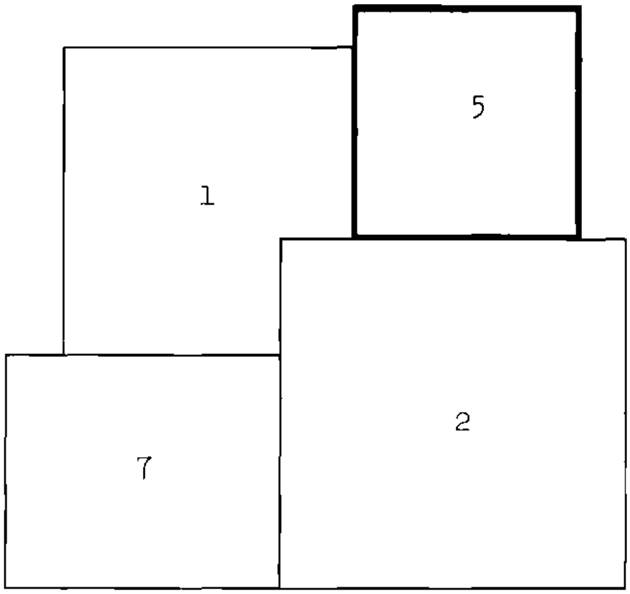
A few terms need to be defined before the algorithm can be discussed in detail. The term "selection process" will refer to the method used in answering the first question, while "placement process" will refer to the second question. Areas which have not yet been placed in the layout are considered to be "available" and are listed on the "available list." (A further restriction of this term will be presented later under the section on modifications and extensions.) Departments which have been assigned a specific location in the layout have been "placed" and are recorded on the "placed list."

The Selection Methods

The selection process is concerned with the first of the two questions: "What department should be selected next for placement in the layout?" The process used must answer the question in such a way that the resulting layout will have a low materials handling cost. The answer to this question involves the establishment of some selection criteria. A number of methods were investigated in this study, and three alternative methods are included in the final program because of their logical selection of departments. The choice of which method to use to establish a layout is left up to the user; however, it is recommended that all three methods be used to establish different layouts and the resulting layouts compared.



The layout at some point
during the buildup process.



Placement of department number 5

Figure 17. Layout Development--As Implemented
by the PLANET II Algorithm

Method A. The first selection method is based directly on the Flow-Between Cost Chart. First the pair of departments having the highest flow-between cost is selected for placement. Unnecessary separation of these two departments produces a larger penalty or cost than any other pair; therefore it is desirable to insure their placement adjacent to each other.

After the first two departments have been assigned locations, all other departments are selected by the process described below. Pairs of departments are considered for which one department is on the available list and the other department is on the placed list. The pair with the highest flow-between cost is chosen and the member of that pair which was on the available list is considered as the selected department. It is removed from the available list, assigned a location by the placement process and added to the placed list. This procedure is repeated until all of the departments have been assigned a location in the layout.

Figure 18 illustrates this process graphically. The Flow-Between Cost Chart has been normalized so that all values fall between zero and one. This is done purely to clarify the presentation of the chart. Departments 1, 2 and 7 are already in the layout, as indicated by the placed list, and departments 3, 4, 5, and 6 are available for placement. All *columns* except those on the placed list are temporarily crossed off the chart. Next all *rows* except those on the available list are temporarily crossed off. The remaining cells represent all of the pairs of departments that have one member on each list. These cells are searched to find the maximum value in the set. The *row* which contains this value represents the selected department and the *column* represents the department which brought it into the layout.

Available List	Placed List 1	2					7
	X	X	X	X	X	X	X
	X	X	X	X	X	X	X
3	.62	.40	X	X	X	X	.31
4	.05	.63	X	X	X	X	.05
5	.37	.10	X	X	X	X	.72
6	.21	0	X	X	X	X	.31
	X	X	X	X	X	X	X

Figure 18. Selection by Method A--Based on the Maximum Flow-Between Cost Element

Method B. The second selection method is identical to Method A with respect to the first two departments selected. The pair of departments with the highest flow between cost is the initial pair placed in the layout.

The remaining selections are made by relating each department on the available list to all departments on the placed list and then selecting the department with the highest total relationship to those departments in the layout. Consider the example shown in Figure 19. The rows which have not been crossed off are the departments on the available list while the columns remaining represent the placed departments. An "Entrance Relationship" has been added to the chart and each value in this column is calculated by adding the elements of a row that have not been crossed off. Consider department number 3. The Entrance Relationship is calculated by adding the element in that row which represents departments that are already placed.

$$ER_3 = .62 + .40 + .31 = 1.33$$

Available List	Placed List 1	2					7	Entrance Relation
	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X
3	.62	.40	X	X	X	X	.31	1.33
4	.05	.63	X	X	X	X	.05	.73
5	.37	.10	X	X	X	X	.72	1.19
6	.21	0	X	X	X	X	.31	.52
	X	X	X	X	X	X	X	X

Figure 19. Selection by Method B--Based on Highest Entrance Relationship

By selecting the next department to be placed in the layout by this method, the entering department is chosen on the basis of its relation to all of the departments already in the layout.

Method C. A somewhat different approach may be utilized with the latter selection routine. Before any selection has been made, a "Total Department Flow-Between Cost" is calculated for each department by adding elements across each row of the Flow-Between Cost Chart.

The departments are next ranked in descending order based on their TDF-BC value. Figure 20 illustrates the values of TDF-BC obtained for the sample problem and the resulting ranking.

	1	2	3	4	5	6	7	TDF-BC	Rank
1	-	1.00	.62	.05	.37	.21	.62	2.87	3
2	1.00	-	.40	.63	.71	0	.90	3.64	1
3	.62	.40	-	.23	.32	.21	.31	2.09	5
4	.05	.63	.23	-	.40	0	.05	1.36	6
5	.37	.10	.32	.40	-	.20	.72	2.11	4
6	.21	0	.21	0	.20	-	.31	0.93	7
7	.62	.90	.31	105	.72	.31	-	2.91	2

Figure 20. Selection by Method C

The department with the highest TDF-BC value is selected first, the second highest value next, etc., until all departments are in the layout. This method may seem slightly arbitrary until it is realized that this technique tends to place those departments with highest handling costs in the middle of the layout.

Choice of Selection Methods. Because of the intended use of the program, none of the methods above were eliminated from the final program. If the user elects to have each method produce a different layout, he has at his disposal, three different alternatives to aid in the establishment of a final layout. It must be remembered that this program does not pretend to present a final layout, but is only intended to serve as an aid in developing the relative location and orientation of the departments.

The Placement Procedure

As each department is selected for entry into the layout, it must be located in such a way as to maintain a low materials handling cost. The method employed by the program is quite simple. The first two departments to enter the layout are placed side-by-side in the middle of the layout grid. After that, each department that enters is placed into the existing layout in such a position that it will increase the layout handling cost by the smallest amount.

To find the exact location for an entering department a perimeter is first established around the outside of the previously located departments. Points around this perimeter are then assumed to represent the center of the entering department. Materials handling costs between the entering department and the departments already in the layout are then computed for each point in the perimeter using this assumed center to establish the necessary distances. Thus, an entrance cost is associated with the points along the perimeter. The entire perimeter is searched for the minimum cost point. Once the minimum cost point is located, the department is placed in the layout using this point as an approximation of the center of the department.

To compensate for the variation in size of the entering departments, the perimeter actually consists of a number of "rings" around the previously located departments. Since larger departments utilize a ring that is farther from the existing layout than the rings that would be used by smaller departments, the perimeter points more closely approximate the center of a square incoming department than would points taken from a single perimeter ring. Figure 21 illustrates the use of a minimum cost perimeter point in locating a particular department.

Once the center of the selected department is fixed, the blocks are added to the layout by a spiral or leaping process as indicated in Figure 22. This method of placement was used to insure a relatively square shape, the user must establish the exact shape desired when he adjusts the layout to conform to a logical building configuration.

Although this placement method tends to place departments in the best possible location as they enter, it in no way guarantees an optimal solution, since a department which is in the layout is not allowed to shift or adjust to entering departments.

The Output

There are three components of the computer output:

1. A listing of the input data is produced for visual verification of the input data cards. Often input errors will produce very misleading output results.

2. A printout of the From-To Chart and the Flow-Between Cost Chart. These charts should be of great value to the user in adjusting and revising the spatial arrangements.

3. A printout of each of the final spatial arrangements produced by the three different selection methods utilized in the algorithm.

The form is similar to the layouts produced by other computer programs in that departments are represented by a number of unit blocks

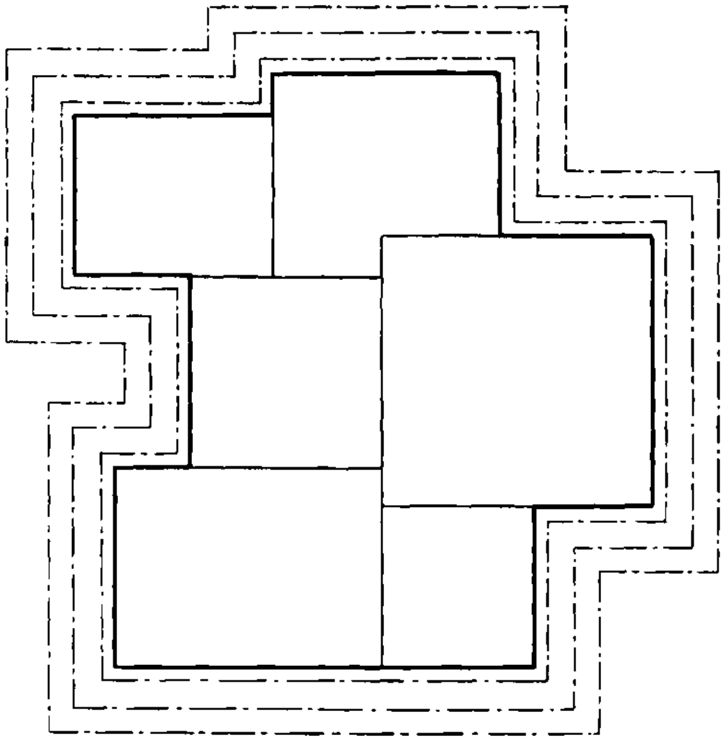


Figure 21. Multiple Perimeter Rings Surrounding a Partial Layout

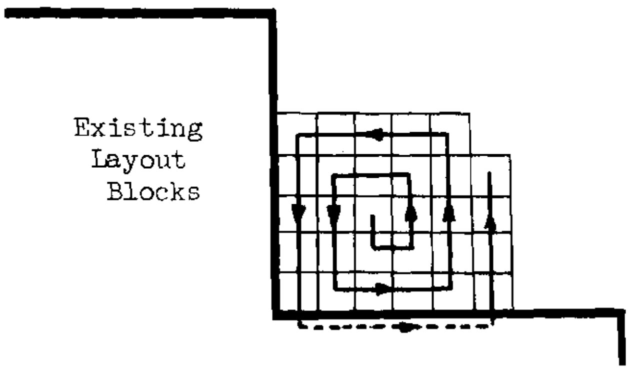


Figure 22. The Spiraling Routine Placing Department Blocks

arranged on a grid system. If the user so desires, intermediate layouts can be printed as each department is added to the layout. The final layout includes the materials handling cost associated with the given arrangement as well as a listing of the order in which departments entered the layout. A sample problem along with the output is included in Appendix III.

Modifications and Extensions

One modification was added to the basic program in order to handle special departments. It may be desirable to save some departments for placement until everything else has been arranged. A priority system is used with the area input data. Departments with priority values of one are arranged first. After they are entered, departments with a value of two are added, etc. The example in Appendix III utilizes this modification.

A second modification was made in the form of acceptable input data. The user may already have a From-To Chart and not wish to utilize the Parts List format, or he may wish to utilize some other form of penalty matrix. The model was modified to accept either one of these forms in place of the Parts List. A complete description of input data formats is presented in Appendix II.

CHAPTER IV

CONCLUSIONS

The most significant contribution presented in this program is found in the input data requirements. Fundamentally the program is centered around the flow of materials within the facility. Not only must the sequence of operations of each part be specified, but also the expected volume and cost of movement of each part must be given. Existing programs assume that a summary of this data exists or they discount the importance of it altogether. Since materials handling plays such a significant role in the establishment of plant layouts, it was deemed necessary to include it as a controlling factor in the computerized layout routines.

A second contribution can be found in the selection and placement routines. Three logical methods of selecting departments for placement are included in the program. Each method attempts to bring departments into the layout in such a manner that large material flows will be over short distances. The placement routine aids the selection routine in this process by finding the best possible location for departments as they enter. Additionally the multiple perimeter rings and the spiral placement routine attempt to provide relatively compact department shapes, a feat not obtained in some existing layout programs.

Finally the resulting layout demands interaction from the layout engineer. The spatial arrangement *must* be molded into a logical building configuration. PLANET II is at best an aid in establishing a layout of a production facility. It does not consider all of the factors necessary in producing a layout. It is up to the layout engineer to integrate the suggestions given by the program with the additional facts available, such as subjective consideration suggested by experience with similar layout problems.

APPENDICES

APPENDIX I

LISTING OF FORTRAN PROGRAM

```
*   *   *  MAIN FORTRAN PROGRAM  *   *   *

C     THIS PROGRM CONTROLS THE SELECTION OF THE VARIOUS SUBROUTINES.
C     THE INPUT SUBROUTINE IS FIRST CALLED TO INPUT THE NECESSARY
C     DATA CARDS.
      CALL INPUT (NDPTS,NDPAVL,KSEL1,KSEL2,KSEL3)
      IF (KSEL1.EQ.0)  GO TO 200
      CALL SEL1 (NDPTS,NDPAVL,KSEL1)
  200 CONTINUE
      IF (KSEL2.EQ.0)  GO TO 300
      CALL SEL2 (NDPTS,NDPAVL,KSEL2)
  300 CONTINUE
      IF (KSEL3.EQ.0)  GO TO 400
      CALL SEL3 (NDPTS,NDPAVL,KSEL3)
  400 CONTINUE
      STOP
      END


*   *   *  INPUT SUBROUTINE  *   *   *

      SUBROUTINE INPUT(NDPTS,NDPAVL,KSEL1,KSEL2,KSEL3)
      DIMENSION TITLE(7), REMARK(11),MVSQ(99)
      INTEGER BLANK
      COMMON /BLKA/ CSTMAT(99,99)
     *       /BLKB/ NBLKS(99)
     *       /BLKE/ KPRIOR(99)
     *       /BLKF/ KLASS(9)
     *       /BLKG/ KSYM(99),BLANK
  101 FORMAT (I1,I2,A3,I2,7A6,I2,F8.0,A2,I2,3I2)
  102 FORMAT (I1,A2,F8.0,I2,11A6)
  103 FORMAT (I1,A4,I2,I3,F10.0,30A2)
  104 FORMAT (I1,A2,I2,15F5.0)
  105 FORMAT (I1,A2,I1,38F2.0)
  501 FORMAT (1H+,I5,1X,A3,I3,/,47X,7A6,////,4X,23HNUMBER OF DEPARTMENTS
     * =,I3,//,4X,17HUNIT BLOCK SIZE =,F10.2,//)
  502 FORMAT (4X,42HINPUT DATA IS IN THE FORM OF A PARTS LIST.,//)
  503 FORMAT (4X,45HINPUT DATA IS IN THE FORM OF A FROM-TO CHART.,//)
  504 FORMAT (4X,47HINPUT DATA IS IN THE FORM OF A PENALITY MATRIX.,//)
  505 FORMAT (4X,34HTHE TYPE OF SELECTION METHOD USED:)
  506 FORMAT (/,10X,6HTYPE 1)
```

```
507 FORMAT (/,10X,6HTYPE 2)
508 FORMAT (/,10X,6HTYPE 3)
510 FORMAT (//,49X,25HINPUT DATA FOR DEPARTMENT,/,53X,17HBLOCK ALLOCAT
   *IONS,//)
511 FORMAT (66(2H -),/,11X,62HDEPARTMENT    REQUIRED     NUMBER OF
   *PRIORITY        REMARKS,/,13X,33HSYMBOL          AREA           BLOCKS,
   */,66(2H -),/)
512 FORMAT (15X,A2,7X,F8.0,8X,I4,10X,I2,10X,11A6,/)
513 FORMAT (/,49X,25HINPUT DATA FOR PARTS LIST,/)
514 FORMAT (66(2H -),/,8X,45HPART   FREQUENCY    COST/MOVE    MOVE SEQU
   *ENCE,/,9X,29HNO      OF MOVE     PER 100 FT.,/,66(2H -))
515 FORMAT (/,8X,A4,5X,I3,6X,E10.4,4X,30(A2,1X))
516 FORMAT (/,4X,A2,3X,15F8.5)
517 FORMAT (1H+,44X,24HNORMALIZED FROM-TO CHART,15X, E14.7,  ///,5X,15
   *(6X,A2),/)
518 FORMAT (50X,19HPENALITY INPUT DATA,//,18H  DEPT    PENALITY,/)
519 FORMAT (3X,A2,4X,38(1X,I2))
520 FORMAT (/)
521 FORMAT (30X,35H NORMALIZED FLOW-BETWEEN COST CHART,15X,E14.7,///,
   *5X,15(6X,A2),/)
522 FORMAT (/,4X,A2,15F8.4)
523 FORMAT (5X,10H THERE ARE,I3,39H DEPARTMENTS AVAILABLE FOR ARRANGEM
   *ENT.,)
524 FORMAT (1H+,18X,55HA LAYOUT WILL BE PRINTED ONLY AFTER THE LAST IT
   *ERATION.,/)
525 FORMAT (1H+,18X,46HA LAYOUT WILL BE PRINTED AFTER EACH ITERATION.,
   */)
901 FORMAT (//,66(2H *),//,130H ERROR NUMBER 001 -- THE PROGRAM DID NO
   *T FIND THE PROPER LABEL NUMBER IN THE CARD LABEL COLUMN FOR THE LA
   *YOUT SPECIFICATION CARD. ,//,66(2H *))
902 FORMAT (//,66(2H *),//,131H ERROR NUMBER 002 -- THE PROGRAM DID NO
   *T FIND THE STATED NUMBER OF DEPARTMENT AREA CARDS BEFORE ENCOUNTER
   *ING A NEW LABEL IN COL 1. ,//,66(2H *))
903 FORMAT (10(3H **),4X11HDEPARTMENT ,A2,36H WILL NOT APPEAR IN THE F
   *INAL LAYOUT,3X,10(3H **),/,10(3H **),4X,51HSINCE THE AREA REQUIRED
   * FOR IT IS LESS THAN A BLOCK ,1X,10(3H **),/)
904 FORMAT (//,66(2H *),//,113H ERROR NUMBER 004 -- THE PROGRAM FAILED
   *TO FIND THE PROPER LABEL NUMBER IN THE FIRST COLUMN OF A PARTS LIS
   *T CARD. ,//,66(2H *))
905 FORMAT (10(3H **),4X,91HTHE ABOVE CARD HAS AN INVALID NUMBER IN TH
   *E SIXTH AND SEVENTH COLUMNS AND IS BEING IGNORED.,/)
906 FORMAT (10(3H **),4X,36HTHE ABOVE MOVE SEQUENCE CONTAINS A ',A2,50
   *H' WHICH WAS NOT LISTED AS A DEPARTMENT IDENTIFIER.,/)
907 FORMAT (//,66(2H *),//,110H ERROR NUMBER 007 -- THE PROGRAM FAILED
   *TO FIND THE PROPER LABEL NUMBER IN THE FIRST COLUMN OF A FROM-TO C
   *ARD. ,//,66(2H *))
908 FORMAT (//,66(2H *),//,121H ERROR NUMBER 008 -- THE DATA CARDS FOR
   *THE FROM-TO CHART DO NOT LIST THE DEPARTMENTS IN THE SAME ORDER AS
   *THE AREA CARDS. ,//,66(2H *))
909 FORMAT (//,66(2H *),//, 53H ERROR NUMBER 009 -- THE DATA CARDS WIT
   *HIN DEPARTMENT ,A2,32H ARE NOT IN THE PROPER SEQUENCE.,//,66(2H *)
   *)
910 FORMAT (//,66(2H *),//,84H ERROR NUMBER 010 -- THE PROGRAM HAS FOU
   *ND THE MAXIMUM COST VALUE TO BE NONPOSITIVE. ,//,66(2H *))
911 FORMAT (//,66(2H *),//,112H ERROR NUMBER 011 -- THE PROGRAM DID NO
   *T  FIND THE PROPER LABEL NUMBER IN ONE OF THE PENALITY MATRIX DATA
   * CARDS. ,//,66(2H *))
```

```
  912 FORMAT (//,66(2H *),//, 91H ERROR NUMBER 012 -- THE DATA CARDS IN
     *THE INPUT DATA LISTS ARE NOT IN THE PROPER SEQUENCE. ,//,66(2H *))
  913 FORMAT (//,66(2H *),//,50H ERROR NUMBER 013 -- THE DATA CARDS FOR
     XDEPARTMENT ,A2,30H ARE NOT IN THE CORRECT ORDER. ,//,66(2H *))
      CALL PAGE(KLINES,KPAGE)
C     THIS SECTION OF THE INPUT SUBROUTINE IS USED TO READ THE
C     SPECIFICATION CARD AND THE DEPARTMENT AREA REQUIREMENTS FOR
C     ALL PROBLEMS.  OTHER INPUT DATA IS READ AS INDICATED ON THE
C     SPECIFICATION CARD.
      READ(5,101) L,NDAY,NMONTH,NYEAR,TITLE,NDPTS,BSIZE,BLANK,INPTYP,
     *            KSEL1,KSEL2,KSEL3
      IF (L.EQ.1) GO TO 1000
      WRITE (6,901)
      STOP
 1000 WRITE(6,501) NDAY,NMONTH,NYEAR,TITLE,NDPTS,BSIZE
      IF (INPTYP - 2)  1001,1002,1003
 1001 WRITE (6,502)
      GO TO 1004
 1002 WRITE (6,503)
      GO TO 1004
 1003 WRITE (6,504)
 1004 WRITE (6,505)
      IF (KSEL1.EQ.0) GO TO 1005
      WRITE (6,506)
      IF (KSEL1.EQ.1)  WRITE (6,524)
      IF (KSEL1.EQ.2)  WRITE (6,525)
 1005 IF(KSEL2.EQ.0)GO TO 1006
      WRITE (6,507)
      IF (KSEL2.EQ.1)  WRITE (6,524)
      IF (KSEL2.EQ.2)  WRITE (6,525)
 1006 IF (KSEL3.EQ.0) GO TO 1007
      WRITE (6,508)
      IF (KSEL3.EQ.1)  WRITE (6,524)
      IF (KSEL3.EQ.2)  WRITE (6,525)
 1007 CALL PAGE(KLINES,KPAGE)
      NDPOMT = 0
      WRITE (6,510)
      WRITE (6,511)
      KLINES = 11
C     READ AREA REQUIREMENTS FOR EACH DEPARTMENT.
      DO 1010 I = 1,NDPTS
      READ(5,102) L,KSYM(I),AREA,KPRIOR(I),REMARK
      IF (L.EQ.2) GO TO 1008
      WRITE (6,902)
      STOP
 1008 NBLKS(I) = AREA / BSIZE + 0.5
      IF (KPRIOR(I).EQ.0) KPRIOR(I) = 1
      WRITE (6,512) KSYM(I),AREA,NBLKS(I),KPRIOR(I),REMARK
      KLINES = KLINES + 2
      IF (NBLKS(I).GT.0) GO TO 1009
      KPRIOR(I) = -1
      NDPOMT = NDPOMT + 1
      WRITE (6,903) KSYM(I)
      KLINES = KLINES + 2
 1009 IF (KLINES.LT.50) GO TO 1010
      CALL PAGE(KLINES,KPAGE)
      WRITE (6,511)
```

```
      KLINES = 5
 1010 CONTINUE
      NDPAVL = NDPTS - NDPOMT
      WRITE (6,523) NDPAVL
      DO 1015 ITHD = 1,NDPTS
      IF (KPRIOR(ITHD).EQ.-1) GO TO 1015
      DO 1014 KTH = 1,9
      IF (KPRIOR(ITHD).GT.KTH) GO TO 1014
      KLASS(KTH) = KLASS(KTH) + 1
 1014 CONTINUE
 1015 CONTINUE
C     THE PROGRAM MUST NOW BRANCH ON THE VARIOUS TYPES OF
C     MATERIALS FLOW INPUT DATA.
      IF (INPTYP - 2)  1020,1050,1100
C     THIS SECTION INPUTS MATERIALS FLOW DATA BY USING A PARTS
C     LIST.  THERE IS NO LIMIT TO THE NUMBER OF PARTS THAT MAY
C     BE USED.
 1020 CONTINUE
      CALL PAGE(KLINES,KPAGE)
      WRITE (6,513)
      WRITE (6,514)
      KLINES = 11
 1022 READ (5,103) L,K1,NUM,KFREQ,COST,(MVSQ(J),J=1, 30)
      IF (L.EQ.3) GO TO 1025
      WRITE (6,904)
      STOP
 1025 IF (NUM.EQ.99) GO TO 1065
      WRITE (6,515) K1,    KFREQ,COST,(MVSQ(J),J=1,NUM)
      KLINES = KLINES + 2
      IF (NUM.GT.1 .AND.NUM.LE.30) GO TO 1026
      WRITE (6,905)
      KLINES = KLINES + 2
      GO TO 1036
 1026 COST = COST * FLOAT(KFREQ)
      KHECK = 0
      DO 1027 I = 1,NDPTS
      IF (KSYM(I).NE.MVSQ(1)) GO TO 1027
      ITHD = I
      GO TO 1028
 1027 CONTINUE
      WRITE (6,905) MVSQ(1)
      KLINES = KLINES + 2
      KHECK = -1
 1028 CONTINUE
      DO 1035 K = 2,NUM
      DO 1029 J = 1,NDPTS
      IF (KSYM(J).NE.MVSQ(K)) GO TO 1029
      JTHD = J
      GO TO 1030
 1029 CONTINUE
      WRITE (6,906) MVSQ(K)
      KLINES = KLINES + 2
      KHECK = -2
 1030 IF (KHECK.EQ.0) GO TO 1031
      KHECK = KHECK + 1
      GO TO 1032
 1031 CSTMAT(ITHD,JTHD) = CSTMAT(ITHD,JTHD) + COST
```

```
 1032 ITHD = JTHD
 1035 CONTINUE
 1036 IF (KLINES.LT.50) GO TO 1022
      CALL PAGE(KLINES,KPAGE)
      WRITE (6,514)
      KLINES = 5
      GO TO 1022
C     THIS SECTION INPUTS DATA FROM A FROM-TO CHART. ALL CARDS
C     ARE PROCESSED BEFORE THE CHART IS PRINTED.
 1050 CONTINUE
      DO 1060 ITHD = 1,NDPTS
      KNT = 1
      DO 1055 J = 1,NDPTS,15
      JSTART = J
      JSTOP = J + 14
      IF (JSTOP.GT.NDPTS) JSTOP = NDPTS
      READ (5,104) L,ICHK,JCHK,(CSTMAT(ITHD,JTHD),JTHD=JSTART,JSTOP)
      IF (L.EQ.4) GO TO 1051
      WRITE (6,907)
      STOP
 1051 IF (ICHK.EQ.KSYM(ITHD)) GO TO 1052
      WRITE (6,908)
      STOP
 1052 IF (JCHK.EQ.KNT) GO TO 1055
      WRITE (6,909) ICHK
      STOP
 1055 KNT = KNT + 1
 1060 CONTINUE
C     THIS SECTION WILL TAKE THE COST CHART FROM THE PARTS LIST
C     OR THE FROM-TO CHART DATA AND NORMALIZE IT AND THEN PRINT
C     A COPY.
 1065 CONTINUE
      DO 1070 ITHD = 1,NDPTS
      DO 1069 JTHD = 1,NDPTS
      IF (CSTMAT(ITHD,JTHD).LE.CSTMAX) GO TO 1069
      CSTMAX = CSTMAT(ITHD,JTHD)
 1069 CONTINUE
 1070 CONTINUE
      IF (CSTMAX) 1071,1071,1072
 1071 WRITE (6,910)
      STOP
 1072 CONTINUE
      DO 1075 ITHD = 1,NDPTS
      DO 1075 JTHD = 1,NDPTS
 1075 CSTMAT(ITHD,JTHD) = CSTMAT(ITHD,JTHD) / CSTMAX
C     THIS SECTION PRINTS THE NORMALIZED FROM-TO CHART.
      DO 1080 J = 1,NDPTS,15
      JSTART = J
      JSTOP = J + 14
      IF (JSTOP.GT.NDPTS) JSTOP = NDPTS
      DO 1080 I = 1,NDPTS,25
      ISTART = I
      ISTOP = I + 24
      IF (ISTOP.GT.NDPTS) ISTOP = NDPTS
      CALL PAGE(KLINES,KPAGE)
      WRITE (6,517) CSTMAX,(KSYM(JJ),JJ = JSTART,JSTOP)
      DO 1080 II = ISTART,ISTOP
```

```
 1080 WRITE (6,516) KSYM(II),(CSTMAT(II,JJ),JJ = JSTART,JSTOP)
      GO TO 1140
C     THIS SECTION IS USED TO INPUT THE THIRD TYPE OF DATA.
 1100 CALL PAGE(KLINES,KPAGE)
      WRITE (6,518)
      KLINES = 10
      DO 1110 ITHD = 1,NDPTS
      KNT = 1
      DO 1105 J = 1,NDPTS,38
      JSTART = J
      JSTOP = J + 37
      IF (JSTOP.GT.NDPTS) JSTOP = NDPTS
      READ (5,105) L,ICHK,JCHK,(CSTMAT(ITHD,JTHD),JTHD=JSTART,JSTOP)
      IF (L.EQ.5) GO TO 1101
      WRITE (6,911)
      STOP
 1101 IF (ICHK.EQ.KSYM(ITHD)) GO TO 1102
      WRITE (6,912)
      STOP
 1102 IF (JCHK.EQ.KNT) GO TO 1103
      WRITE (6,913) ICHK
      STOP
 1103 CONTINUE
      I=1
      DO 1104 JTHD=JSTART,JSTOP
      MVSQ(I)=CSTMAT(ITHD,JTHD)
      I=I+1
 1104 CONTINUE
      ISTOP = I-1
      WRITE (6,519) L,ICHK,JCHK,(MVSQ(I),I=1,ISTOP)
      KLINES = KLINES + 1
 1105 KNT = KNT + 1
      WRITE (6,520)
      KLINES = KLINES + 1
      IF (KLINES.LT.52) GO TO 1110
      CALL PAGE(KLINES,KPAGE)
      WRITE (6,518)
      KLINES = 5
 1110 CONTINUE
      DO 1125 ITHD = 1,NDPTS
      DO 1124 JTHD = 1,NDPTS
      IF (CSTMAT(ITHD,JTHD).LE.CSTMAX) GO TO 1124
      CSTMAX = CSTMAT(ITHD,JTHD)
 1124 CONTINUE
 1125 CONTINUE
      DO 1130 ITHD = 1,NDPTS
      DO 1130 JTHD = 1,NDPTS
 1130 CSTMAT(ITHD,JTHD) = CSTMAT(ITHD,JTHD) / CSTMAX
 1140 CONTINUE
      NDPTM1 = NDPTS - 1
      DO 1150 ITHD = 1,NDPTM1
      DO 1150 JTHD = ITHD,NDPTS
      CSTMAT(ITHD,JTHD) = CSTMAT(ITHD,JTHD) + CSTMAT(JTHD,ITHD)
 1150 CSTMAT(JTHD,ITHD) = CSTMAT(ITHD,JTHD)
      DO 1160 J = 1,NDPTS,15
      JSTART = J
      JSTOP = J + 14
```

```
      IF (JSTOP.GT.NDPTS) JSTOP = NDPTS
      DO 1160 I = 1,NDPTS,25
      ISTART = I
      ISTOP = I + 24
      IF (ISTOP.GT.NDPTS) ISTOP = NDPTS
      CALL PAGE(KLINES,KPAGE)
      WRITE (6,521) CSTMAX,(KSYM(JJ),JJ = JSTART,JSTOP)
      DO 1160 II = ISTART,ISTOP
      WRITE (6,522) KSYM(II),(CSTMAT(II,JJ),JJ=JSTART,JSTOP)
 1160 CONTINUE
      RETURN
      END


*  *  *  PAGE NUMBERING SUBROUTINE  *  *  *

      SUBROUTINE PAGE (KLINES,KPAGE)
C     THIS SUBROUTINE CAUSES THE PRINTER TO START A NEW PAGE AND
C     NUMBER THEM IN CONSECUTIVE ORDER. THE LINE COUNT IS SET TO
C     ZERO.
      KPAGE = KPAGE + 1
      KLINES = 0
      WRITE(6,1) KPAGE
    1 FORMAT(1H1,120X,4HPAGE,I4)
      RETURN
      END


*  *  *  SELECTION METHOD A SUBROUTINE  *  *  *

      SUBROUTINE SEL1 (NDPTS,NDPAVL,KSEL1)
C     THIS SUBROUTINE SELECTS THE NEXT DEPARTMENT TO ENTER THE
C     LAYOUT BASED ON THE MAXIMUM COST BETWEEN A DEPARTMENT THAT
C     IS IN THE LAYOUT AND A DEPARTMENT THAT IS NOT IN THE LAYOUT.
      COMMON /BLKA/CSTMAT(99,99)
     *       /BLKD/KSTATE(99)
     *       /BLKE/KPRIOR(99)
     *       /BLKF/KLASS(9)
      DIMENSION LISTOR(99)
      NDILAY = 0
 1010 CALL CLEAR
      DO 1015 ITHD=1,NDPTS
 1015 KSTATE(ITHD) = KPRIOR(ITHD)
      LPRI = 0
 1016 LPRI = LPRI + 1
      IF (KLASS(LPRI).LT.2) GO TO 1016
      CSTMAX = 0
      N = NDPTS - 1
      DO 1025 ITHD=1,N
      IF (KSTATE(ITHD).GT.LPRI.OR.KSTATE(ITHD).LT.0)  GO TO 1025
      J = ITHD + 1
      DO 1020 JTHD=J,NDPTS
      IF (KSTATE(JTHD).GT.LPRI.OR.KSTATE(JTHD).LT.0)  GO TO 1020
      IF (CSTMAX.GT.CSTMAT(ITHD,JTHD))GO TO 1020
      ITHDMX = ITHD
```

```
      JTHDMX = JTHD
      CSTMAX = CSTMAT(ITHD,JTHD)
 1020 CONTINUE
 1025 CONTINUE
      INDEPT = ITHDMX
      CALL PLACE (NDILAY,INDEPT,NDPTS,TLYCST)
      LISTOR(NDILAY) = INDEPT
      IF (KSEL1.EQ.2) CALL OUTPUT(TLYCST,NDILAY,NDPAVL,LISTOR)
 1030 INDEPT = JTHDMX
      CALL PLACE (NDILAY,INDEPT,NDPTS,TLYCST)
      LISTOR(NDILAY) = INDEPT
      IF (KSEL1.EQ.2) CALL OUTPUT(TLYCST,NDILAY,NDPAVL,LISTOR)
 1035 CSTMAX = 0
C     THIS SECTION SELECTS ALL DEPARTMENTS AFTER THE FIRST TWO
C     HAVE BEEN PLACED IN THE LAYOUT.
 1037 IF (NDILAY.LT.KLASS(LPRI)) GO TO 1040
      LPRI = LPRI + 1
      GO TO 1037
 1040 CONTINUE
      DO 1045 ITHD=1,NDPTS
      IF (KSTATE(ITHD).GT.LPRI.OR.KSTATE(ITHD).LE.0) GO TO 1045
      DO 1043 JTHD=1,NDPTS
      IF (KSTATE(JTHD).NE.0) GO TO 1043
      IF (CSTMAX.GT.CSTMAT(ITHD,JTHD)) GO TO 1043
      ITHDMX = ITHD
      CSTMAX = CSTMAT(ITHD,JTHD)
 1043 CONTINUE
 1045 CONTINUE
      INDEPT =ITHDMX
      CALL PLACE (NDILAY,INDEPT,NDPTS,TLYCST)
      LISTOR(NDILAY) = INDEPT
      IF (KSEL1.EQ.2) CALL OUTPUT(TLYCST,NDILAY,NDPAVL,LISTOR)
      IF (NDILAY.LT.NDPAVL) GO TO 1035
      IF (KSEL1.EQ.1) CALL OUTPUT(TLYCST,NDILAY,NDPAVL,LISTOR)
      RETURN
      END
```

* * * SELECTION METHOD B SUBROUTINE * * *

```
      SUBROUTINE SEL2 (NDPTS,NDPAVL,KSEL2)
C     THIS SUBROUTINE UTILIZES THE RELATIONSHIP BETWEEN ONE
C     DEPARTMENT NOT IN THE LAYOUT AND ALL THE DEPARTMENTS
C     IN THE LAYOUT.
      COMMON /BLKA/CSTMAT(99,99)
     *        /BLKD/KSTATE(99)
     *        /BLKE/KPRIOR(99)
     *        /BLKF/KLASS(9)
      DIMENSION LISTOR(99)
      NDILAY = 0
 1010 CALL CLEAR
      DO 1015 ITHD=1,NDPTS
 1015 KSTATE(ITHD) = KPRIOR(ITHD)
      LPRI = 0
 1016 LPRI = LPRI + 1
      IF (KLASS(LPRI).LT.2) GO TO 1016
```

```
      N = NDPTS - 1
      DO 1025 ITHD=1,N
      IF (KSTATE(ITHD).GT.LPRI.OR.KSTATE(ITHD).LT.0) GO TO 1025
      J = ITHD + 1
      DO 1020 JTHD=J,NDPTS
      IF (KSTATE(JTHD).GT.LPRI.OR.KSTATE(JTHD).LT.0) GO TO 1025
      IF (CSTMAX.GT.CSTMAT(ITHD,JTHD))GO TO 1020
      ITHDMX = ITHD
      JTHDMX = JTHD
      CSTMAX = CSTMAT(ITHD,JTHD)
 1020 CONTINUE
 1025 CONTINUE
      INDEPT = ITHDMX
      CALL PLACE (NDILAY,INDEPT,NDPTS,TLYCST)
      LISTOR(NDILAY) = INDEPT
      IF (KSEL2.EQ.2) CALL OUTPUT(TLYCST,NDILAY,NDPAVL,LISTOR)
 1030 INDEPT = JTHDMX
      CALL PLACE (NDILAY,INDEPT,NDPTS,TLYCST)
      LISTOR(NDILAY) = INDEPT
      IF (KSEL2.EQ.2) CALL OUTPUT(TLYCST,NDILAY,NDPAVL,LISTOR)
 1035 CSTMAX = 0
C     THIS SECTION SELECTS ALL DEPARTMENT AFTER THE FIRST TWO
C     HAVE BEEN ENTERED IN THE LAYOUT.
 1037 IF (NDILAY.LT.KLASS(LPRI))GO TO 1040
      LPRI = LPRI + 1
      GO TO 1037
 1040 CONTINUE
      DO 1050 ITHD=1,NDPTS
      IF (KSTATE(ITHD).LE.0.OR.KSTATE(ITHD).GT.LPRI) GO TO 1050
      DEPCST = 0
      DO 1045 JTHD=1,NDPTS
      IF (KSTATE(JTHD).NE.0) GO TO 1045
      DEPCST = DEPCST + CSTMAT(ITHD,JTHD)
 1045 CONTINUE
      IF (DEPCST.LT.CSTMAX) GO TO 1050
      ITHDMX = ITHD
      CSTMAX = DEPCST
 1050 CONTINUE
      INDEPT = ITHDMX
      CALL PLACE (NDILAY,INDEPT,NDPTS,TLYCST)
      LISTOR(NDILAY) = INDEPT
      IF (KSEL2.EQ.2) CALL OUTPUT(TLYCST,NDILAY,NDPAVL,LISTOR)
      IF (NDILAY.LT.NDPAVL) GO TO 1035
      IF (KSEL2.EQ.1) CALL OUTPUT(TLYCST,NDILAY,NDPAVL,LISTOR)
      RETURN
      END
```

* * * SELECTION METHOD C SUBROUTINE * * *

```
      SUBROUTINE SEL3 (NDPTS,NDPAVL,KSEL3)
C     THIS SUBROUTINE SELECTS THE ENTERING DEPARTMENTS BASED ON
C     AN ORDERED LIST OF THEIR RELATION TO THE OTHER DEPARTMENTS.
      DIMENSION LIST(99),TDPCST(99)
      DIMENSION LISTOR(99)
      COMMON /BLKA/CSTMAT(99,99)
```

```
      *        /BLKD/KSTATE(99)
      *        /BLKE/KPRIOR(99)
      *        /BLKF/KLASS(9)
       NDILAY = 0
 1010  CALL CLEAR
       DO 1020 ITHD=1,NDPTS
       DO 1015 JTHD=1,NDPTS
 1015  TDPCST(ITHD) = TDPCST(ITHD) + CSTMAT(ITHD,JTHD)
       LIST(ITHD) = ITHD
 1020  KSTATE(ITHD) = KPRIOR(ITHD)
       LASTK = NDPTS + 1
 1026  LASTK = LASTK - 1
       DO 1030 K=2,LASTK
       I = LIST(K-1)
       J = LIST(K)
       IF (TDPCST(J).LT.TDPCST(I)) GO TO 1030
       LIST(K) = I
       LIST(K-1) = J
 1030  CONTINUE
       IF (LASTK.NE.2) GO TO 1026
       LASTK = NDPTS + 1
 1031  LASTK = LASTK - 1
       DO 1035 K=2,LASTK
       I = LIST(K-1)
       J = LIST(K)
       IF (KSTATE(J).GE.KSTATE(I)) GO TO 1035
       LIST(K-1) = J
       LIST(K) = I
 1035  CONTINUE
       IF (LASTK.NE.2) GO TO 1031
       DO 1040 I=1,NDPTS
       K = LIST(I)
       IF (KSTATE(K).NE.-1) GO TO 1045
 1040  CONTINUE
 1045  KTHD = I-1
 1050  KTHD = KTHD + 1
       INDEPT = LIST(KTHD)
       CALL PLACE (NDILAY,INDEPT,NDPTS,TLYCST)
       LISTOR(NDILAY) = INDEPT
       IF (KSEL3.EQ.2) CALL OUTPUT(TLYCST,NDILAY,NDPAVL,LISTOR)
       IF (NDILAY.LT.NDPAVL) GO TO 1050
       IF (KSEL3.EQ.1) CALL OUTPUT(TLYCST,NDILAY,NDPAVL,LISTOR)
       RETURN
       END


*  *  *  LAYOUT CLEARING SUBROUTINE  *  *  *

       SUBROUTINE CLEAR
C      THIS SUBROUTINE CLEARS THE LAYOUT MATRIX
       COMMON /BLKC/ LAYOUT(100,100),MAXI,MAXJ,MINI,MINJ
       DO 1100 I=1,100
       DO 1100 J=1,100
 1100  LAYOUT(I,J) = 0
       RETURN
       END
```

* * * PRINTOUT SUBROUTINE * * *

```
      SUBROUTINE OUTPUT(TLYCST,NDILAY,NDPAVL,LISTOR)
C     THIS SUBROUTINE PRINTS THE LAYOUTS AS REQUESTED BY THE USER.
      INTEGER BLANK
      DIMENSION LINE(40)
      DIMENSION LISTOR(99)
      COMMON /BLKC/ LAYOUT(100,100),MAXI,MAXJ,MINI,MINJ
     *       / BLKG / KSYM(99),BLANK
  100 FORMAT (1H1,55X,6HLAYOUT,10X,E14.7,//)
  101 FORMAT (5X,40(1X,A2),/)
  102 FORMAT (1H1,40X,20H LEFT HALF OF LAYOUT,//)
  103 FORMAT (1H1,40X,21H RIGHT HALF OF LAYOUT,10X,E14.7,//)
  104 FORMAT (28H THE ORDER OF PLACEMENT WAS ,30(A2,1X),/,13X,35(A2,1X),
     */,13X,35(A2,1X))
      DO 1010 L=1,40
 1010 LINE(L) = BLANK
      K = MAXJ - MINJ + 1
      IF (K.GT.40) GO TO 1050
      WRITE(6,100) TLYCST
      DO 1040 I = MINI,MAXI
      L = 20 - K/2
      DO 1030 J = MINJ,MAXJ
      L = L + 1
      NUM = LAYOUT(I,J)
      IF (NUM.LE.0) GO TO 1020
      LINE(L) = KSYM(NUM)
      GO TO 1030
 1020 LINE(L) = BLANK
 1030 CONTINUE
 1040 WRITE (6,101)(LINE(K),K=1,40)
      IF (NDILAY.EQ.NDPAVL) GO TO 2000
      RETURN
 1050 WRITE (6,102)
      DO 1080 I = MINI,MAXI
      DO 1070 J = MINJ,50
      NUM = LAYOUT(I,J)
      IF (NUM.LE.0) GO TO 1060
      LINE(J) = KSYM(NUM)
      GO TO 1070
 1060 LINE(J) = BLANK
 1070 CONTINUE
 1080 WRITE (6,101) (LINE(K),K=1,40)
      WRITE(6,103) TLYCST
      DO 1110 I = MINI,MAXI
      DO 1100 J = 51,MAXJ
      L = J - 50
      NUM = LAYOUT(I,J)
      IF (NUM.LE.0) GO TO 1090
      LINE(L) = KSYM(NUM)
      GO TO 1100
 1090 LINE(L) = BLANK
 1100 CONTINUE
 1110 WRITE (6,101) (LINE(K),K=1,40)
      IF (NDILAY.EQ.NDPAVL) GO TO 2000
```

```
      RETURN
 2000 DO 2010 I=1,NDILAY
      J = LISTOR(I)
 2010 LISTOR(I) = KSYM(J)
      NUM = NDILAY + 1
      DO 2020 I=NUM,99
 2020 LISTOR(I) = BLANK
      WRITE(6,104) LISTOR
      RETURN
      END
```

```
*  *  *  PLACEMENT SUBROUTINE  *  *  *

      SUBROUTINE PLACE (NDILAY, INDEPT, NDPTS, TLYCST)
C     THIS SUBROUTINE PLACES THE DEPARTMENTS IN THE EXISTING
C     LAYOUT. INDEPT IS THE INCOMING DEPARTMENT.
      DIMENSION DEPTMD(99,2),IJPER(900,2)
      COMMON /BLKA/ CSTMAT(99,99)
     *       /BLKB/ NBLKS(99)
     *       /BLKC/ LAYOUT(100,100),MAXI,MAXJ,MINI,MINJ
     *       /BLKD/ KSTATE(99)
      IF (NDILAY-1) 1010,1100,1200
 1010 KTHD = INDEPT
C     THIS SECTION PLACES THE FIRST DEPARTMENT IN THE MIDDLE OF A
C     BLANK LAYOUT.
      IMID = 50
      JMID = 50
      NBLK = NBLKS(INDEPT)
      NBSD = SQRT(NBLK)
      NBRM = NBLK - NBSD ** 2
      IFST = IMID - NBSD / 2
      ILST = IFST + NBSD - 1
      JFST = JMID - NBSD + 1
      JLST = JFST + NBSD - 1
      KSUMI = 0
      KSUMJ = 0
      DO 1020 I = IFST,ILST
      DO 1020 J = JFST,JLST
      KSUMI = KSUMI + I
      KSUMJ = KSUMJ + J
 1020 LAYOUT(I,J) = INDEPT
      MINI = IFST
      MAXI = ILST
      MINJ = JFST
      MAXJ = JMID
      IF (NBRM.EQ.0) GO TO 1050
 1030 NJ = JFST - 1
 1031 CONTINUE
      MINJ = NJ
      DO 1040 I = IFST,ILST
      KSUMI = KSUMI + I
      KSUMJ = KSUMJ + NJ
      LAYOUT(I,NJ) = INDEPT
      NBRM = NBRM - 1
      IF (NBRM.EQ.0) GO TO 1050
```

```
 1040 CONTINUE
      NJ = NJ - 1
      GO TO 1031
 1050 CONTINUE
      KSTATE(INDEPT) = 0
      AUX1 = KSUMI
      AUX2 = KSUMJ
      AUX3 = NBLK
      DEPTMD(INDEPT,1) = AUX1 / AUX3
      DEPTMD(INDEPT,2) = AUX2 / AUX3
      NDILAY = NDILAY + 1
      RETURN
 1100 CONTINUE
C     THIS SECTION PLACES THE SECOND DEPARTMENT IN THE LAYOUT.
C     ADJACENT TO THE FIRST DEPARTMENT.
      NBLK = NBLKS(INDEPT)
      NBSD = SQRT(NBLK)
      NBRM = NBLK - NBSD ** 2
      IFST = IMID - NBSD / 2
      ILST = IFST + NBSD - 1
      JFST = JMID + 1
      JLST = JFST + NBSD - 1
      KSUMI = 0
      KSUMJ = 0
      DO 1110 I = IFST,ILST
      DO 1110 J = JFST,JLST
      KSUMI = KSUMI + I
      KSUMJ = KSUMJ + J
 1110 LAYOUT(I,J) = INDEPT
      IF (IFST.LT.MINI) MINI = IFST
      IF (ILST.GT.MAXI) MAXI = ILST
      MAXJ = JLST
      IF (NBRM.EQ.0) GO TO 1140
      NJ = JLST + 1
 1120 MAXJ = NJ
      DO 1130 I = IFST,ILST
      KSUMI = KSUMI + I
      KSUMJ = KSUMJ + NJ
      LAYOUT(I,NJ) = INDEPT
      NBRM = NBRM - 1
      IF (NBRM.EQ.0) GO TO 1140
 1130 CONTINUE
      NJ = NJ + 1
      GO TO 1120
 1140 CONTINUE
      KSTATE(INDEPT) = 0
      AUX1 = KSUMI
      AUX2 = KSUMJ
      AUX3 = NBLK
      DEPTMD(INDEPT,1) = AUX1 / AUX3
      DEPTMD(INDEPT,2) = AUX2 / AUX3
      XI = DEPTMD(KTHD,1)
      XJ = DEPTMD(KTHD,2)
      YI = DEPTMD(INDEPT,1)
      YJ = DEPTMD(INDEPT,2)
      DST = ABS(XI-YI) + ABS(XJ-YJ)
      TLYCST = CSTMAT(KTHD,INDEPT) * DST
```

```
      NDILAY = NDILAY + 1
      RETURN
 1200 COSMIN = 2 ** 27
      IFST = MINI - 6
      ILST = MAXI + 6
      JFST = MINJ - 6
      JLST = MAXJ + 6
      IF (IFST.LT.1) IFST = 1
      IF (JFST.LT.1) JFST = 1
      DO 1210 I = IFST,ILST
      DO 1210 J = JFST,JLST
      IF (LAYOUT(I,J).LT.0) LAYOUT(I,J)=0
 1210 CONTINUE
      NBRM = NBLKS(INDEPT)
      DO 1213 I=2,5
      INDEX = I - 1
      ITEST = (I * 2 - 1) ** 2
      IF (NBRM.LT.ITEST) GO TO 1214
 1213 CONTINUE
      INDEX = 5
 1214 INDXP = -1
 1215 NBLKIP = 0
      I = MINI + INDXP
      JFST = MINJ + INDXP
      DO 1220 J = JFST,80
      IF (LAYOUT(I+1,J+1).NE.0) GO TO 1225
 1220 CONTINUE
 1225 NBLKIP = NBLKIP + 1
      IJPER(NBLKIP,1) = I
      IJPER(NBLKIP,2) = J
      LAYOUT(I,J) = INDXP
      KPB = 1
 1230 I = IJPER(KPB,1)
      J = IJPER(KPB,2)
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      IDUM1 = -1
      IDUM2 =  1
      DO 1260 II = IM1,IP1
      DO 1260 JJ = JM1,JP1
      IDUM2 = IDUM1 * IDUM2
      IF (IDUM2.EQ.-1) GO TO 1260
      IF (LAYOUT(II,JJ).NE.0) GO TO 1260
      IIM1 = II - 1
      IIP1 = II + 1
      JJM1 = JJ - 1
      JJP1 = JJ + 1
      DO 1240 III = IIM1,IIP1
      DO 1240 JJJ = JJM1,JJP1
      IF (LAYOUT(III,JJJ).EQ.0) GO TO 1240
      IF (LAYOUT(III,JJJ).GT.INDXP) GO TO 1250
 1240 CONTINUE
      GO TO 1260
 1250 NBLKIP = NBLKIP + 1
      IF (NBLKIP.GT.900) STOP
```

```
      IJPER(NBLKIP,1) = II
      IJPER(NBLKIP,2) = JJ
      LAYOUT(II,JJ) = INDXP
 1260 CONTINUE
      IF (KPB.EQ.NBLKIP) GO TO 1270
      KPB = KPB + 1
      GO TO 1230
 1270 IF (INDEX + INDXP) 1275,1280,1275
 1275 INDXP = INDXP - 1
      GO TO 1215
 1280 CONTINUE
      DO 1320 K = 1,NBLKIP
      CST = 0
      XI = IJPER(K,1)
      XJ = IJPER(K,2)
      DO 1310 KTHD =1,NDPTS
      IF (KSTATE(KTHD).NE.0) GO TO 1310
      YI = DEPTMD(KTHD,1)
      YJ = DEPTMD(KTHD,2)
      DST = ABS(XI-YI) + ABS(XJ-YJ)
 1300 CST = CSTMAT(KTHD,INDEPT) * DST + CST
 1310 CONTINUE
      IF (CST.GT.COSMIN) GO TO 1320
      COSMIN = CST
      KBEST = K
 1320 CONTINUE
      KFLAG = 0
      I = IJPER(KBEST,1)
      J = IJPER(KBEST,2) -1
      JDT = 1
      IDT = 0
      K1I = 0
      K1J = 0
      KONTI = 0
      KONTJ = 0
      KSUMI = 0
      KSUMJ = 0
C     GENERAL PLACEMENT PROCEDURE.
 1400 I = I + IDT
      J = J + JDT
      IF (I.LE.9.OR.I.GT.90) GO TO 1440
      IF (J.LT.9.OR.J.GT.90) GO TO 1440
      IF (LAYOUT(I,J).GT.0) GO TO 1440
      IF (KFLAG.EQ.0) GO TO 1420
C     THIS SECTION TESTS FOR CONTIQUITY
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 1410 II = IM1,IP1
      DO 1410 JJ = JM1,JP1
      IF (LAYOUT(II,JJ).EQ.INDEPT) GO TO 1420
 1410 CONTINUE
      GO TO 1440
 1420 LAYOUT(I,J) = INDEPT
      KFLAG = 0
 1430 CONTINUE
```

```
      KSUMI = KSUMI + I
      KSUMJ = KSUMJ + J
      NBRM = NBRM - 1
      IF (I.LT.MINI) MINI = I
      IF (I.GT.MAXI) MAXI = I
      IF (J.LT.MINJ) MINJ = J
      IF (J.GT.MAXJ) MAXJ = J
      IF (NBRM.EQ.0) GO TO 1490
      GO TO 1441
 1440 KFLAG = 1
 1441 CONTINUE
C     THIS SECTION SELECTS THE NEXT BLOCK TO BE TESTED.
      IF (KONTI.NE.K1I) GO TO 1460
      KONTI = 0
      IF (IDT.EQ.0) GO TO 1450
      IDT = 0
      GO TO 1460
 1450 IDT = (-1) ** (K1I + 2)
      K1I = K1I + 1
 1460 KONTI = KONTI + 1
      IF (KONTJ.NE.K1J) GO TO 1480
      KONTJ = 0
      IF (JDT.EQ.0) GO TO 1470
      K1J = K1J + 1
      JDT = 0
      GO TO 1480
 1470 JDT = (-1) ** (K1J + 1)
 1480 KONTJ = KONTJ + 1
      GO TO 1400
 1490 CONTINUE
      AUX1 = KSUMI
      AUX2 = KSUMJ
      AUX3 = NBLKS(INDEPT)
      DEPTMD(INDEPT,1) = AUX1 / AUX3
      DEPTMD(INDEPT,2) = AUX2 / AUX3
      XI = DEPTMD(INDEPT,1)
      XJ = DEPTMD(INDEPT,2)
      DO 1510 KTHD = 1,NDPTS
      IF (KSTATE(KTHD).NE.0) GO TO 1510
      YI = DEPTMD(KTHD,1)
      YJ = DEPTMD(KTHD,2)
      DST = ABS(XI-YI) + ABS(XJ-YJ)
      TLYCST = TLYCST + CSTMAT(KTHD,INDEPT) * DST
 1510 CONTINUE
      KSTATE(INDEPT) = 0
      NDILAY = NDILAY + 1
      RETURN
      END
```

APPENDIX II

PREPARATION OF INPUT

This appendix discusses the input data that must be provided for the program. There are five different types of cards that may be submitted and they are divided into three general categories: run data cards, departmental requirements cards and flow specification cards.

Run Data Cards

Each PLANET II run must contain a single run data card which specifies:

1. The layout name or title.
2. The number of departments to be included in the layout.
3. The size of a unit block.
4. The options desired for this run.

There is only one acceptable format for this card and a description of the field specifications is given below (see Figure 23).

Column

1 The identification code 1 must be entered.

2-8 The date of the computer run, or any other date may be entered. This date will appear in the output. The date is entered in the form DDMMMYY where DD is the day of the month, MMM is the month and YY is the year.

9-50 The layout title to be printed in the printout.

51-52 The number of departments to be entered in the layout. This number must be less than or equal to 99.

Column

53-60 The size of a unit block in square units. It may be any square unit the user desires so long as the unit agrees with the area specification on the departmental requirements card. This field must be right justified and may contain a decimal point.

61-62 These two columns must be blank.

63-64 A numeric code is entered to identify the type of materials flow data that is being entered.

- 01 Flow data is in the form of a Parts List.
- 02 Flow data is in the form of a From-To Chart.
- 03 Flow data is in the form of a Penalty Matrix.

65-66
67-68
69-70 A different selection flag field is available for each selection method available. Columns 65 and 66 are for selection Method A, 67 and 68 are for Method B, and 69 and 70 are for Method C. The numeric code present in each field will determine if that particular method is desired and what printout option should be used.

- 00 Do not use the selection method designated by this field.
- 01 Use the selection method indicated by this field and print a layout after the last department is placed in the layout.
- 02 Use the selection method indicated by this field and print a layout after each department is entered in the layout.

Departmental Requirements Cards

Each PLANET II run must contain one departmental requirements card for each department to be considered in the run. This number of departments must agree with the number of departments indicated on the run data card. Each departmental requirements card specifies

1. The name as a description of the department.
2. The department number or identifier.
3. The area requirements for the department.
4. The priority of placement (optional).

There is only one acceptable format for the departmental requirements card and the details are given below (see Figure 24).

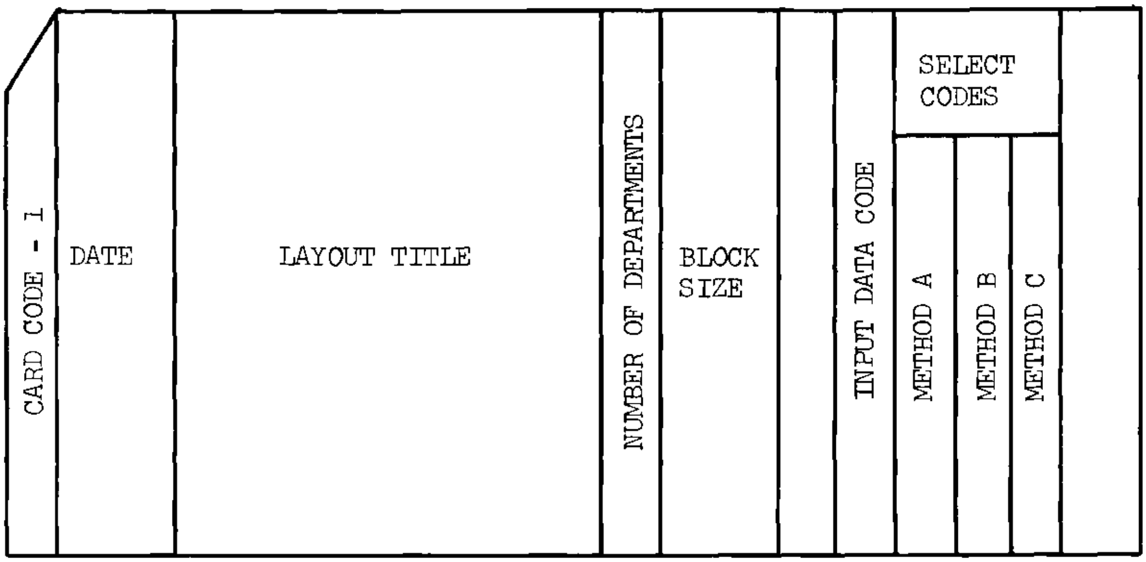


Figure 23. Run Data Card Format

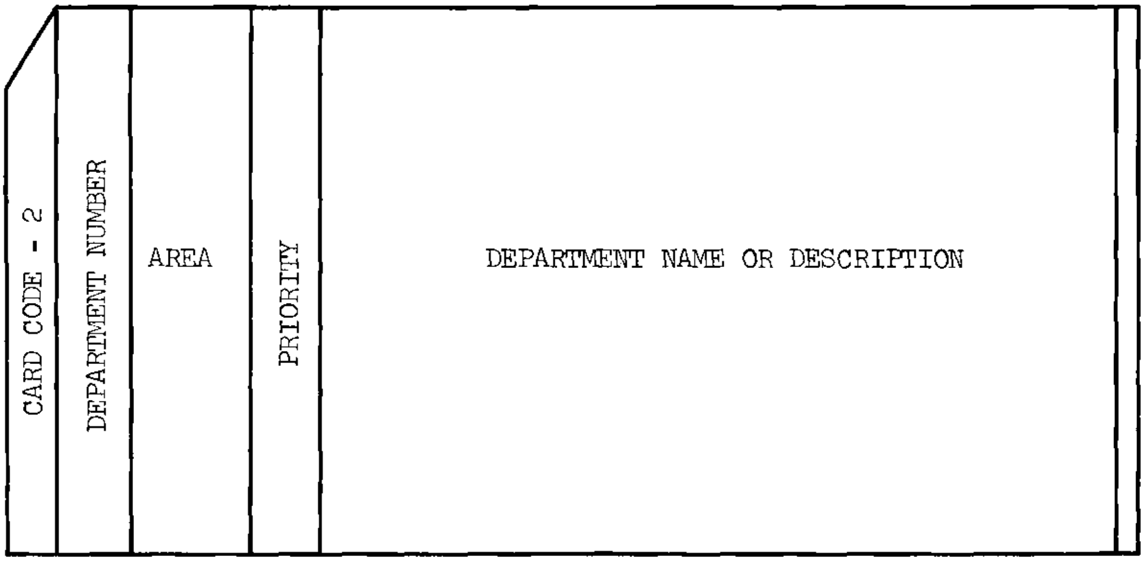


Figure 24. Departmental Requirements Card Format

Column

1 The identification code 2 must be entered.

2-3 The department number or identifier must be entered as it is going to appear on the printed layouts. Any combination of letters or numbers may be used.

4-11 The area required for the department is entered in this field and must be right justified. It may contain a decimal point. The unit of measure must agree with the unit utilized to designate the unit block size on the run data card.

12-79 The department name or description may be entered in this field.

Flow Specification Cards

Each PLANET II run must contain information on the material flowing through the facility; however there are three possible formats for inputing this information.

Parts List Cards

The user may elect to enter his data in the form of a parts list, as indicated in Appendix III. If this option is desired, columns 63-64 of the run data card should contain a 01. Any number of parts list cards can be entered; however the last data card *must* be followed by a trailer card with 99 punched in columns 6-7. The format specifications for parts list cards is given below (see Figure 25).

Column

1 The identification code 3 must be entered.

2-5 The part number or identifier must be entered as it is going to appear on the printout. Any combination of letters, numbers or special characters may be utilized.

6-7 The number of departments listed in the move sequence must be entered in this field, right justified. This number must be less than or equal to 30. If more departments are necessary,

Column

the sequence must be broken and two or more parts list cards utilized to describe the specific part.

8-10 The frequency of movement must be entered in this field, right justified. The unit of time considered must be constant for all parts and is the unit of time considered when the total handling cost is printed.

11-20 The cost per move per hundred units of distance traveled is entered in this field, right justified. The unit of travel should be consistent with the area units utilized earlier in the block size specification and the departmental area requirements. The field may contain a decimal point and is assumed to be in dollars.

21-22
23-24
25-26
...
79-80 These 30 fields contain the move sequence by utilizing the department numbers or identifiers specified on the departmental requirements cards. The number of departments entered must correspond to the number indicated in columns 6-7.

From-To Chart Cards

The user may already possess data in the form of a From-To Chart and wish to utilize this as input. The number of cards required by this format is a multiple of the number of departments and depends on the number of cards necessary to enter the data for a single department. The cards must be sequenced on departments first and in the *same order* as the departmental specifications cards. Within a department, cards must be sequenced by the card numbers indicated in columns 4-5.

Column

1 The identification code 4 must be entered.

2-3 The department number or identifier must be entered in this field for all cards which contain segments of the given departments row in the From-To Chart.

4-5 All From-To Chart cards for a given department must be grouped together and numbered in columns 4-5 starting with 01 and proceeding until the last card for that department is completed.

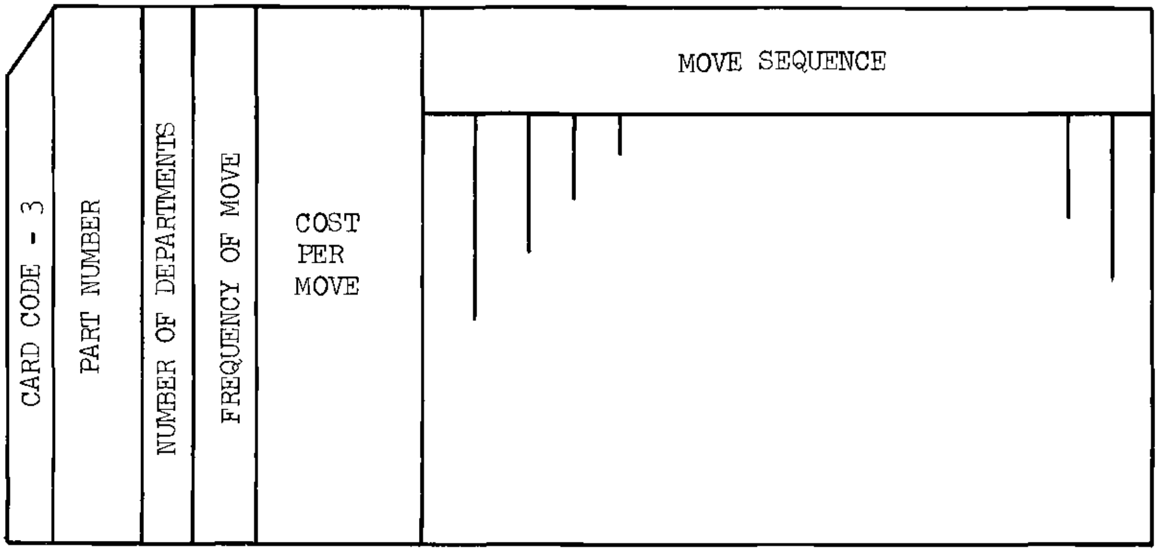


Figure 25. Parts List Card Format

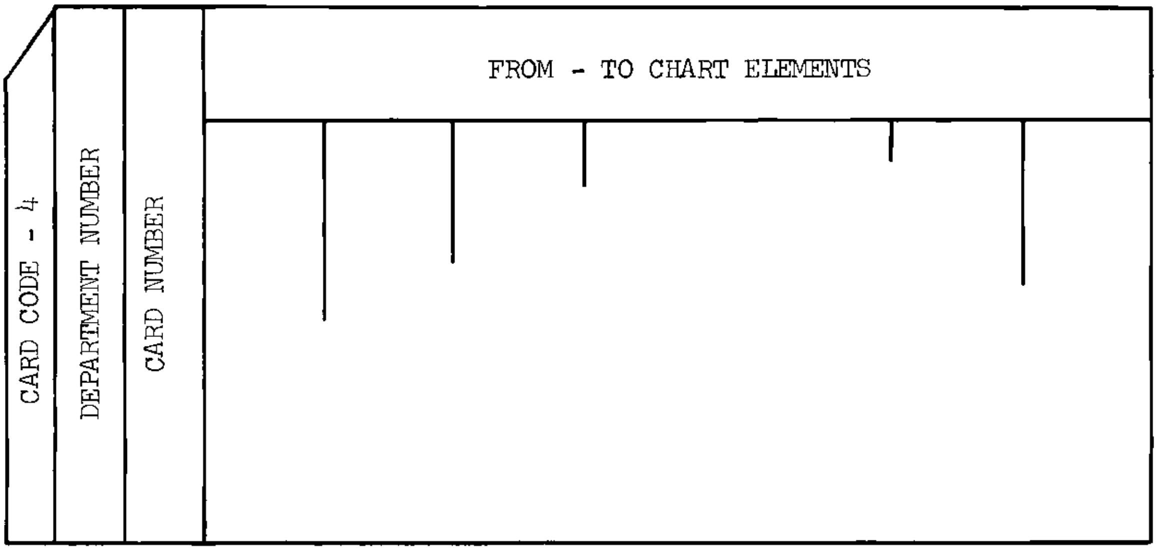


Figure 26. From-To Chart Card Format

Column

(The departmental sequence in identifying rows must match the sequence in identifying columns.)

6-10 These 15 fields represent elements from the From-To Chart. For
11-15 card 01 (columns 6-7) the fields represent the elements of
16-20 columns 1 through 15 of the From-To Chart, for card 02 they
21-25 represent the elements of columns 16 through 30, etc.
...
76-80

Penalty Matrix Cards

A final form of input data that may be entered is the penalty matrix (Figure 27). It should be remembered that the program is trying to minimize a summation of the products of the distances and elements of this matrix; hence a large penalty value for a given element will cause the program to try to locate the indicated departments close together. The number of cards required by this input format is a multiple of the number of departments included in the run. The cards must be grouped first by departments and in the same order as the departmental specifications cards. Within a department, cards must be sequenced by the card number indicated in column 4.

Column

1 The identification code 5 must be entered.

2-3 The department number or identifier must be entered in this field for all cards which contain segments of the given departments row of the Penalty Matrix.

4 All Penalty Matrix cards for a given department must be grouped together and numbered in column 4 starting with 1 and proceeding until the last card for that department is completed.

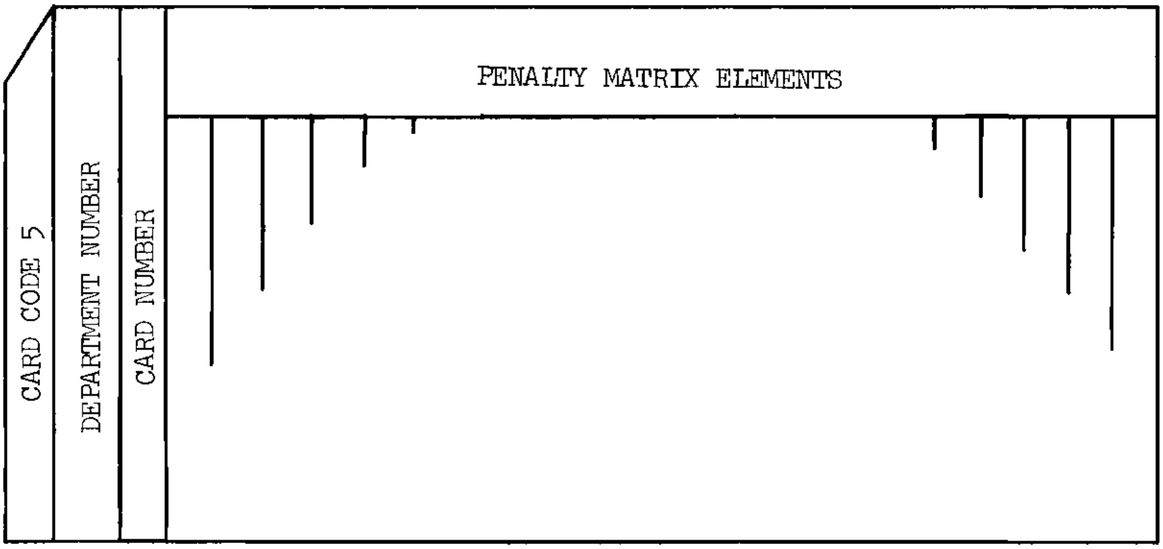


Figure 27. Penalty Matrix Card Format

Column

5-6	These 38 fields represent elements from the Penalty Matrix. For
7-8	card 1 these fields represent the elements of columns 1 through
9-10	38 of the Penalty Matrix, for card 2 they represent the elements
11-12	of columns 39 through 76, etc.
...	
79-80	

Input Data Deck

The input data deck for a run utilizing a Parts List is shown in Figure 28. From-To Chart cards or Penalty Matrix cards would be substituted for the Parts List cards if the user desired to use flow data in one of these optional format.

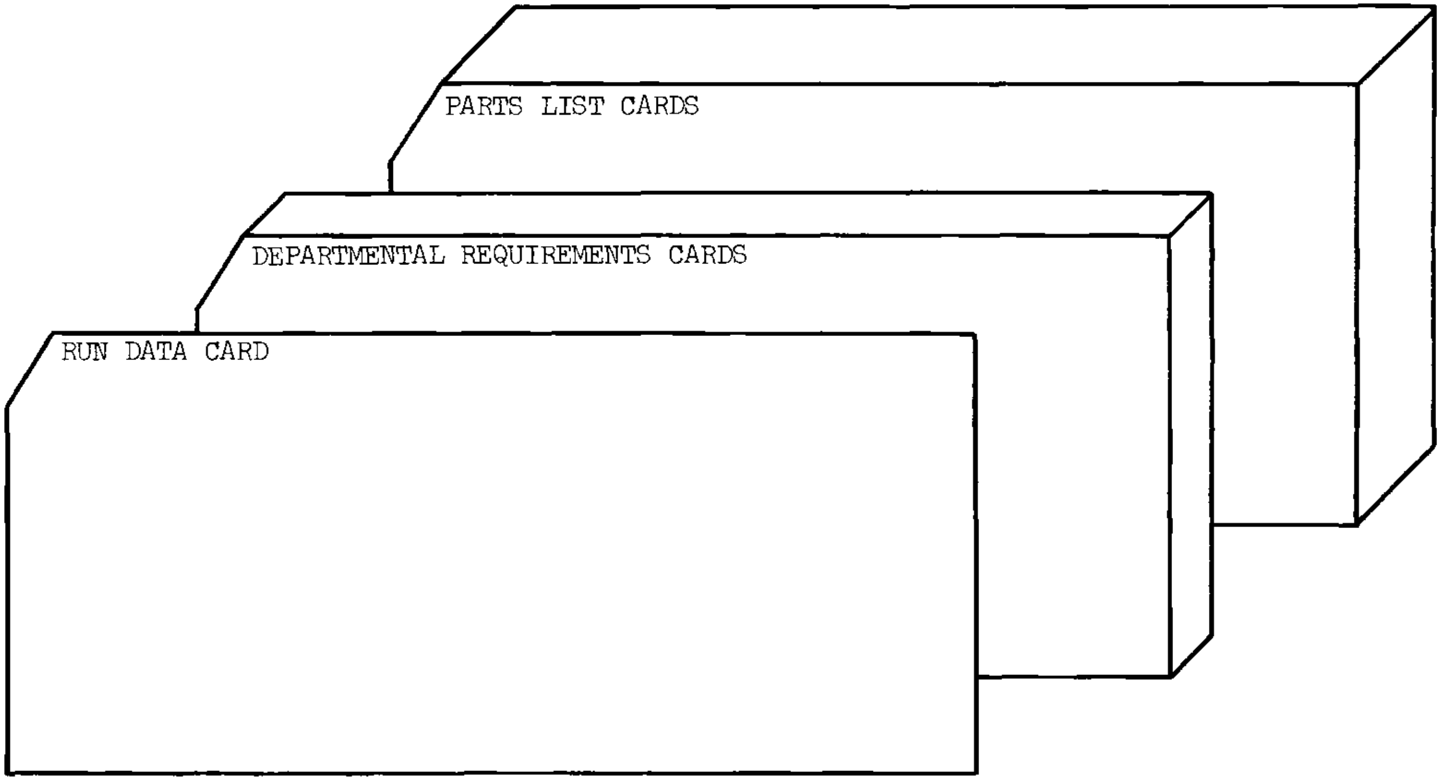


Figure 28. Input Data Deck

APPENDIX III

A SAMPLE PROBLEM

This appendix describes the application of the program to the determination of a departmental arrangement for a plant producing air compressors at a rate of 80,000 per year.

A list of the required production departments is given in Table 1 along with the floor area necessary for each department.

Table 1. Area Requirements for All Production Areas

Dept. No.	Department	Required Area (sq.ft.)
1	Rough Stores	729
2	Mill	984
3	Lathe	3944
4	Drill	1229
5	Grinder	234
6	Press	301
7	Hone	45
8	Saw	138
9	Bore	120
10	Final Inspection	468

It is assumed that material will be moved by one of three possible methods based on the weight of a unit load as indicated in Table 2.

Table 2. Handling Methods

Unit Load Weight (lbs.)	Method of Handling	Cost/Move per 100 ft.
0 - 25	A—Man .	$0.010
25 - 500	B—Walkie Pallet Lift	0.015
500 - Up	C—Fork Truck Lift	0.025

It is also assumed that each part will be moved in lots of 100 parts. The cost figures given in Table 2 are only meant to be representative of the different methods. More accurate estimates should be obtained when entering this data for actual applications.

The parts of the compressors to be made in this plant are listed in Table 3 and the flow sequence of each part is shown in Table 4, these tables being used to prepare the input deck, as described in Appendix II. A complete listing of the input deck is given in Figure 29. The first card is the run data card; the next ten cards are departmental requirements cards. Departments 1 and 10 were given a second class priority to insure a location on an outside wall. The remaining cards are parts list cards. Note that a trailer card is necessary when entering data from a parts list.

Figures 30, 31, and 32 show that output listings of the information contained on the data cards. Figure 31 indicates that all departments are "available for arrangement," meaning that each department is presented by at least one unit block.

Table 3. Parts Data

Part No.	Name	Weight (100 pcs.)	Handling Method	$/Move per 100 ft.	Daily Production	Moves per Day
1	Crankcase	1100	C	0.025	400	4
2	Cylinder	500	C	0.025	400	4
3	Cylinder Bead	300	B	0.015	400	4
4	Crankshaft	150	B	0.015	400	4
5	Connecting Rod	75	B	0.015	400	4
6	Piston	50	B	0.015	400	4
7	Piston Pin	12.5	A	0.010	400	4
12	Outside Bearing	12.5	A	0.010	800	8
13	Inside Bearing	15	A	0.010	400	4
14	Breather	50	B	0.015	400	4
15	Flywheel	1800	C	0.025	400	4
16	Cover Plate	12.5	A	0.010	400	4
18	Suction Fitting	12.5	A	0.010	800	8
19	Discharge Fitting	12.5	A	0.010	400	4
20	Valve	38	B	0.015	400	4
21	Cover Gasket	12.5	A	0.010	1200	12
34	Breather Plate	12.5	A	0.010	400	4

Table 4. Parts Flow Sequence

Part No.	Name	Move Sequence
1	Crankcase	1-2-3-6-4-10
2	Cylinder	1-3-4-7-10
3	Cylinder Bead	1-3-4-10
4	Crankshaft	1-8-3-2-4-10
5	Connecting Rod	1-5-4-9-4-2-6-4-6-10
6	Piston	1-3-4-10
7	Piston Pin	1-8-3-5-10
12	Outside Bearing	1-3-10
13	Inside Bearing	1-3-10
14	Breather	1-2-4-10
15	Flywheel	1-3-6-10
16	Coverplate	1-6-10
18	Suction Fitting	1-3-10
19	Discharge Fitting	1-3-2-10
20	Valve	1-6-10
21	Cover Gasket	1-6-10
34	Breather Plate	1-6-10

```
110FEB71SAMPLE PROBLEM FOR THESIS - AIRCOMPRESSOR 10     25   01010101
2 1      729 2ROUGH STORES
2 2      984 1MILL
2 3     3944 1LATHE
2 4     1229 1DRILL
2 5      234 1GRINDER
2 6      301 1PRESS
2 7       45 1HONE
2 8      138 1SAW
2 9      120 1BORE
210      468 2FINAL INSPECTION
3   1 6  4     0.025 1 2 3 6 410
3   2 5  4     0.025 1 3 4 710
3   3 4  4     0.015 1 3 410
3   4 6  4     0.015 1 8 3 2 410
3   510  4     0.015 1 5 4 9 4 2 6 4 610
3   6 4  4     0.015 1 3 410
3   7 5  4     0.010 1 8 3 510
3  12 3  8     0.010 1 310
3  13 3  4     0.010 1 310
3  14 4  4     0.015 1 2 410
3  15 4  4     0.025 1 3 610
3  16 3  4     0.010 1 610
3  18 3  8     0.010 1 310
3  19 4  4     0.010 1 3 210
3  20 3  4     0.015 1 610
3  21 3 12     0.010 1 610
3  34 3  4     0.010 1 610
3    99             THIS IS THE TRAILER CARD FOR THE PARTS LIST DATA.
```

Figure 29. A Listing of the Input Cards for the Sample Problem

If some departments are smaller than a unit block, the program would not consider them for placement. Figures 33 and 34 are printouts of the From-To Chart and the Flow-Between Cost Chart, respectively. These charts are normalized and a true value for each element can be found by multiplying each element by the normalization factor given above the table. (.560000+00 represents $.56 \times 10^{0}$.)

Figures 35, 36, and 37 indicate the final arrangements developed by the different selection methods. Two observations should be made about these arrangements. First, since the program is attempting to have relatively square departments, holes may be present in a layout. Second, even though the selection methods use different decision rules for the selection of the next department, they can result in the same layouts as indicated by Figures 35 and 36.

This sample problem used 17.893 seconds of computer time on a Univac 1108. The cost of such processing would be approximately $3.00 at the present charge.

10 FEB 71 SAMPLE PROBLEM FOR THESIS - AIRCOMPRESSOR PAGE 1

```
NUMBER OF DEPARTMENTS = 10
UNIT BLOCK SIZE =    25.00

INPUT DATA IS IN THE FORM OF A PARTS LIST.

THE TYPE OF SELECTION METHOD USED:
     TYPE 1   A LAYOUT WILL BE PRINTED ONLY AFTER THE LAST ITERATION.
     TYPE 2   A LAYOUT WILL BE PRINTED ONLY AFTER THE LAST ITERATION.
     TYPE 3   A LAYOUT WILL BE PRINTED ONLY AFTER THE LAST ITERATION.
```

Figure 30. Printout of Information from Run Data Card

INPUT DATA FOR DEPARTMENT
BLOCK ALLOCATIONS

DEPARTMENT SYMBOL	REQUIRED AREA	NUMBER OF BLOCKS	PRIORITY	REMARKS
1	729.	29	2	ROUGH STORES
2	984.	39	1	MILL
3	3944.	158	1	LATHE
4	1229.	49	1	DRILL
5	234.	9	1	GRINDER
6	301.	12	1	PRESS
7	45.	2	1	HONE
8	138.	6	1	SAW
9	120.	5	1	BORE
10	468.	19	2	FINAL INSPECTION

THERE ARE 10 DEPARTMENTS AVAILABLE FOR ARRANGEMENT.

Figure 31. Printout of Information from Departmental Requirements Cards

INPUT DATA FOR PARTS LIST

PART NO	FREQUENCY OF MOVE	COST/MOVE PER 100 FT.	MOVE SEQUENCE
1	4	.2500-01	1 2 3 6 4 10
2	4	.2500-01	1 3 4 7 10
3	4	.1500-01	1 3 4 10
4	4	.1500-01	1 8 3 2 4 10
5	4	.1500-01	1 5 4 9 4 2 6 4 6 10
6	4	.1500-01	1 3 4 10
7	4	.1000-01	1 8 3 5 10
12	8	.1000-01	1 3 10
13	4	.1000-01	1 3 10
14	4	.1500-01	1 2 4 10
15	4	.2500-01	1 3 6 10
16	4	.1000-01	1 6 10
18	8	.1000-01	1 3 10
19	4	.1000-01	1 3 2 10
20	4	.1500-01	1 6 10
21	12	.1000-01	1 6 10
34	4	.1000-01	1 6 10

Figure 32. Printout of Information from Parts List Cards

NORMALIZED FROM-TO CHART .5600000+00 PAGE 4

	1	2	3	4	5	6	7	8	9	10
1	.00000	.28571	1.00000	.00000	.10714	.46429	.00000	.17857	.00000	.00000
2	.00000	.00000	.17857	.21429	.00000	.10714	.00000	.00000	.00000	.07143
3	.00000	.17857	.00000	.39286	.07143	.35714	.00000	.00000	.00000	.35714
4	.00000	.10714	.00000	.00000	.00000	.10714	.17857	.00000	.10714	.60714
5	.00000	.00000	.00000	.10714	.00000	.00000	.00000	.00000	.00000	.07143
6	.00000	.00000	.00000	.28571	.00000	.00000	.00000	.00000	.00000	.75000
7	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.17857
8	.00000	.00000	.17857	.00000	.00000	.00000	.00000	.00000	.00000	.00000
9	.00000	.00000	.00000	.10714	.00000	.00000	.00000	.00000	.00000	.00000
10	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000

Figure 33. Printout of Normalized From-To Chart

NORMALIZEU FLOW-RETWEEN COST CHART .5600000+00

	1	2	3	4	5	6	7	8	9	10
1	.0000	.2857	1.0000	.0000	.1071	.4643	.0000	.1786	.0000	.0000
2	.2857	.0000	.3571	.3214	.0000	.1071	.0000	.0000	.0000	.0714
3	1.0000	.3571	.0000	.3929	.0714	.3571	.0000	.1786	.0000	.3571
4	.0000	.3214	.3929	.0000	.1071	.3929	.1786	.0000	.2143	.6071
5	.1071	.0000	.0714	.1071	.0000	.0000	.0000	.0000	.0000	.0714
6	.4643	.1071	.3571	.3929	.0000	.0000	.0000	.0000	.0000	.7500
7	.0000	.0000	.0000	.1786	.0000	.0000	.0000	.0000	.0000	.1786
8	.1786	.0000	.1786	.0000	.0000	.0000	.0000	.0000	.0000	.0000
9	.0000	.0000	.0000	.2143	.0000	.0000	.0000	.0000	.0000	.0000
10	.0000	.0714	.3571	.6071	.0714	.7500	.1786	.0000	.0000	.0000

Figure 34. Printout of Normalized Flow-Between Cost Chart

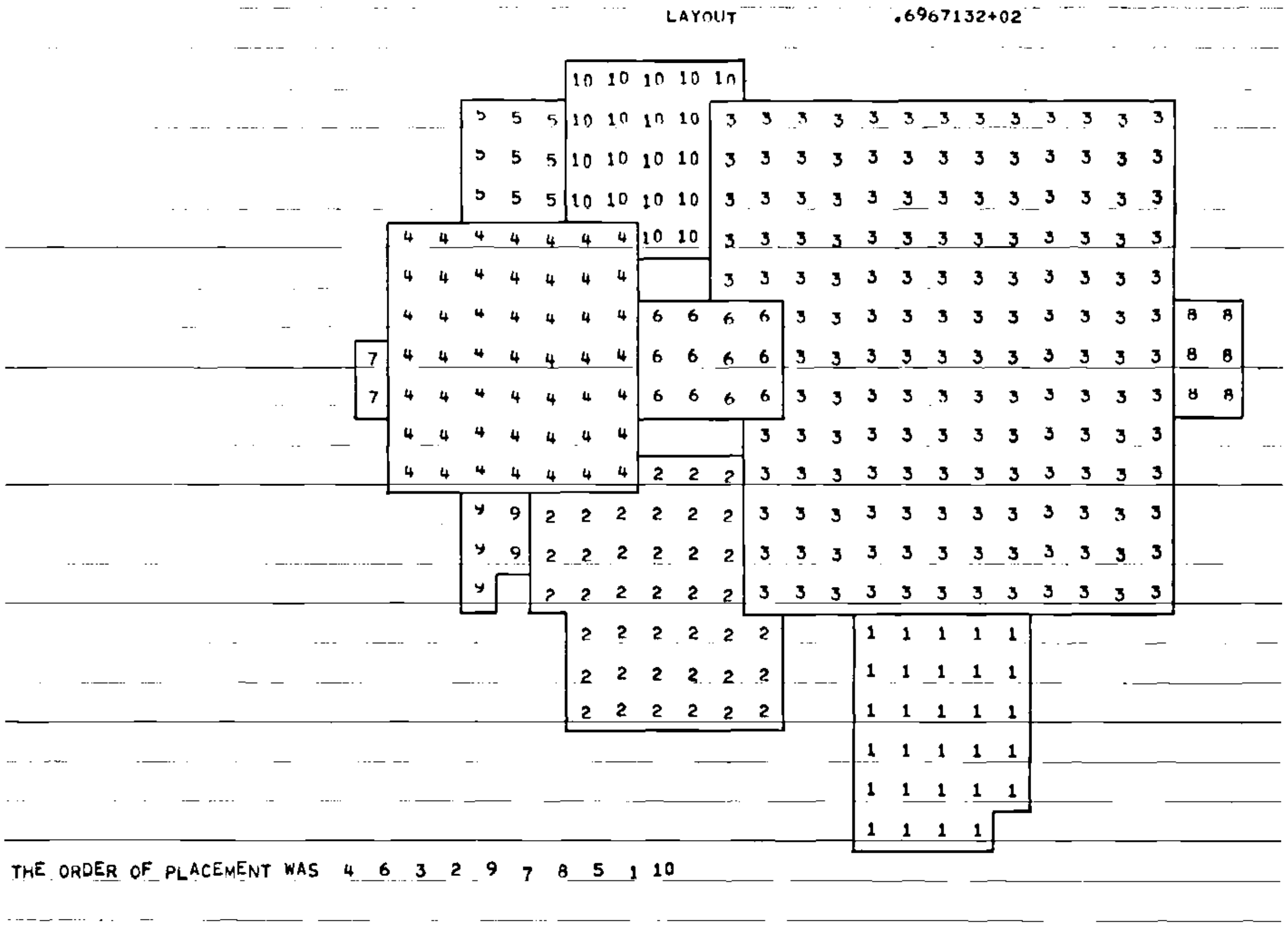
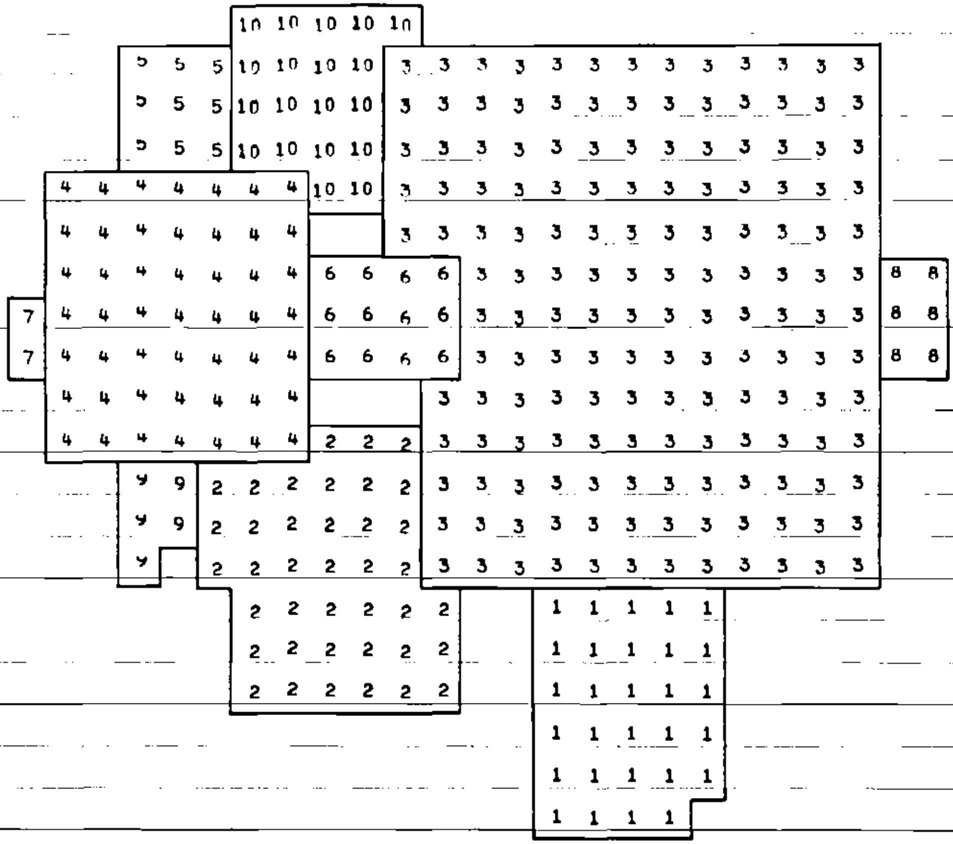


Figure 35. Final Layout Produced by Method A

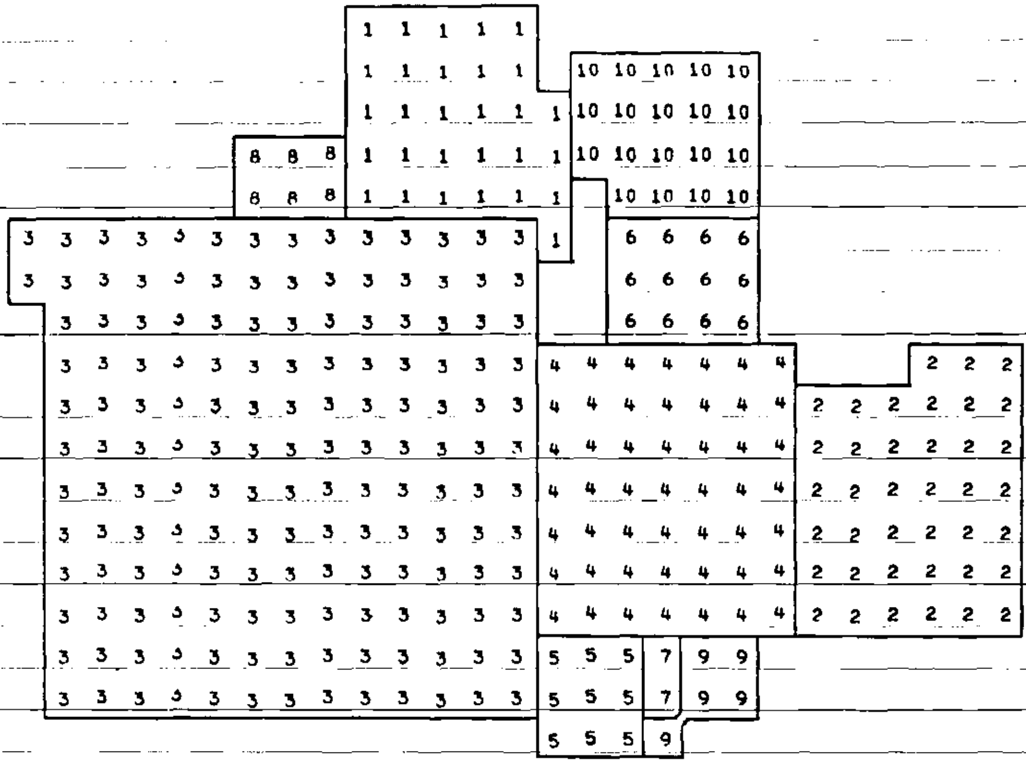
LAYOUT .6967132+02



THE ORDER OF PLACEMENT WAS 4 6 3 2 9 7 8 5 10 1

Figure 36. Final Layout Produced by Method B

LAYOUT .7203576+02



THE ORDER OF PLACEMENT WAS 3 4 6 2 7 5 8 9 10 1

Figure 37. Final Layout Produced by Method C

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BIBLIOGRAPHY

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